



April 2018

MILITARY PERSONNEL

DOD Needs to Reevaluate Fighter Pilot Workforce Requirements

GAO Highlights

Highlights of [GAO-18-113](#), a report to the Committee on Armed Services, U.S. Senate

Why GAO Did This Study

Fighter pilots operate aircraft that are critical to achieving and maintaining air dominance during combat operations. The military services invest significant time and funding to train, compensate, and retain fighter pilots. According to Air Force officials, it costs between \$3-\$11 million and takes approximately 5 years to develop an individual fighter pilot to lead combat missions.

Senate Report 114-255 included a provision for GAO to review the Department of Defense's (DOD) management of the fighter pilot workforce. GAO's report (1) assesses the extent to which the military services had differences in the number of fighter pilots compared to authorizations, and describes any contributing factors as well as initiatives to address the differences, and (2) assesses the extent to which the military services had reevaluated squadron requirements for the number of fighter pilots needed, including consideration of UAS pilot requirements.

GAO analyzed military service personnel data, documentation on service initiatives to address factors contributing to fighter pilot shortages, and service documentation of requirements; met with a non-generalizable sample of fighter pilots at seven locations; and interviewed DOD and service officials.

What GAO Recommends

GAO recommends that the Air Force, the Navy, and the Marine Corps reevaluate fighter pilot squadron requirements. DOD concurred with the recommendations.

View [GAO-18-113](#). For more information, contact Brenda S. Farrell at (202) 512-3604 or farrellb@gao.gov.

April 2018

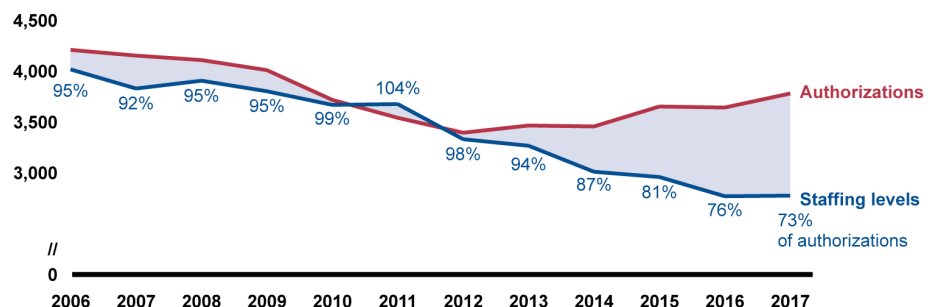
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What GAO Found

The Air Force, the Navy, and the Marine Corps had gaps between the actual numbers of fighter pilots and authorizations (i.e. funded positions) in fiscal years (FY) 2013 through 2017. In FY 2017 the Air Force's gap was the widest at 27 percent of authorizations (see fig. below) and is projected to continue through FY 2023. The Marine Corps' gap grew from 6 percent in FY 2006 to 24 percent in FY 2017; it is concentrated in fighter pilots below the rank of major. While the Navy did not have comparable data, it had a gap at fighter pilots' first operational tours that grew from 12 percent in FY 2013 to 26 percent in FY 2017, and Navy officials stated it could increase through mid-2019. Service officials attributed these gaps to aircraft readiness challenges, reduced training opportunities, and increased attrition of fighter pilots due to career dissatisfaction. To help increase fighter pilot numbers, the military services are taking actions, including increasing the amounts of financial incentives to retain pilots.

Air Force's Active Component Fighter Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017
Personnel



Source: GAO analysis of Air Force data. | GAO-18-113

The military services have not recently reevaluated squadron requirements to reflect increased fighter pilot workload and the emergence of unmanned aerial systems (UAS). According to service guidance, squadron requirements are to be reviewed on a 2-year schedule and to be updated as conditions change (in June 2017 the Navy revised its guidance to extend its schedule from 2 years to 5 years). However, service officials acknowledged that they have not updated all squadron requirements within the last 2 years. These officials stated that the requirements have not been reevaluated because existing conditions do not warrant the change. However, fighter pilots and squadron leaders interviewed at locations GAO visited consistently stated that the typical workload has significantly increased in recent years due to, among other things, changes in fighter aircraft tactics and technology and reductions to administrative support in squadrons. Further, the military services have not assessed the effect of increased reliance on UAS on fighter pilot requirements. The Air Force's vision for UAS notes that systems will work in tandem with cockpit-operated aircraft and that autonomous technologies will potentially lead to personnel efficiencies. Without re-evaluating squadron requirements to reflect current and emerging conditions, the nature of the gap may be inaccurate and thus make it difficult for the military services to target strategies to meet their personnel needs.

Contents

Letter		1
	Background	4
	The Military Services Had Fewer Fighter Pilots Than Authorizations Due to a Variety of Contributing Factors; Initiatives Are Underway to Increase Fighter Pilot Staffing Levels	10
	The Military Services Have Not Reevaluated Fighter Pilot Squadron Requirements to Reflect Changing Conditions, Increased Workload, and Emerging UAS Requirements	23
	Conclusions	28
	Recommendations for Executive Action	28
	Agency Comments	29
Appendix I	Scope and Methodology	30
Appendix II	Comparison of Air Force Pilot Staffing Levels and Authorizations for Fixed-Wing, Cockpit-Operated Aircraft	33
Appendix III	Comparison of Navy Pilot Staffing Levels and Authorizations for Fixed-Wing, Cockpit-Operated Aircraft	41
Appendix IV	Comparison of Marine Corps Pilot Staffing Levels and Authorizations for Fixed-Wing, Cockpit Operated Aircraft	46
Appendix V	Initiatives Implemented by the Air Force to Address Reported Fighter Pilot Shortages	54
Appendix VI	Comments from the Department of Defense	57

Appendix VII	GAO Contact and Staff Acknowledgments	60
Related GAO Products		61
Tables		
	Table 1: Locations Visited for Fighter Pilot Discussion Groups	32
	Table 2: Air Force Fighter Enterprise Tiger Team and Aircrew Crisis Task Force Initiatives Implemented as of November 2017	54
Figures		
	Figure 1: Department of Defense Fighter Aircraft	7
	Figure 2: Explanation of Squadron Requirements, Authorizations, and Pilot Staffing Levels	9
	Figure 3: Air Force's Active Component Fighter Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017	11
	Figure 4: Navy Fighter Pilot First Operational Tour Actual Staffing Levels Compared with Authorizations, Fiscal Years 2013- 2017	13
	Figure 5: Marine Corps' Active Component Fighter Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017	14
	Figure 6: Air Force Fighter Pilot Retention Bonus Take Rate and Maximum Contract Amounts Offered, Fiscal Years 2010- 2017	19
	Figure 7: Navy's Active Duty Fixed-Wing Department Head Pilot Retention Bonus Take Rate, Fiscal Years 2013-2017	20
	Figure 8: Comparison of Air Force's Fixed-Wing Pilot Actual Staffing Levels with Authorizations, Fiscal Year 2017	34
	Figure 9: Air Force's Active Component Fighter Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017	35
	Figure 10: Air Force's Reserve Component Fighter Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017	36

Figure 11: Air Force's Active Component Bomber Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017	37
Figure 12: Air Force's Active Component Mobility Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017	38
Figure 13: Air Force's Active Component Surveillance Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017	39
Figure 14: Air Force's Active Component Special Operations Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017	40
Figure 15: Navy's Active Component Fixed-Wing Pilot Actual Staffing Levels, by Community, Fiscal Years 2011-2017	42
Figure 16: Navy's Active Component Fixed-Wing Pilot First Tour Pilot Actual Staffing Levels Compared with Authorizations for Operational Positions, Fiscal Years 2013-2017	43
Figure 17: Navy's Active Component Fixed-Wing Department Head Milestone Aviator Actual Staffing Levels Compared with Authorizations for Operational Positions, Fiscal Years 2013-2017	44
Figure 18: Navy's Active Component Fixed-Wing Command Milestone Aviator Actual Staffing Levels Compared with Authorizations for Operational Positions, Fiscal Years 2013-2017	45
Figure 19: Marine Corps Fixed-Wing Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Year 2017	47
Figure 20: Marine Corps' Active Component Fighter Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017	48
Figure 21: Marine Corps' Active Component Fighter Pilot Actual Staffing Levels Compared with Operational Positions, Fiscal Years 2006-2017	49
Figure 22: Marine Corps' Reserve Component Fighter Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017	50
Figure 23: Marine Corps' Active Component Junior and Senior Fighter Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Year 2017	51
Figure 24: Marine Corps' Active Component Tiltrotor Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017	52

Figure 25: Marine Corps' Active Component Tanker Pilot Actual
Staffing Levels Compared with Authorizations, Fiscal
Years 2006-2017

53

Abbreviations

DOD	Department of Defense
UAS	unmanned aerial system

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April 11, 2018

The Honorable John McCain
Chairman
The Honorable Jack Reed
Ranking Member
Committee on Armed Services
United States Senate

The Department of Defense (DOD) relies on fighter pilots to perform an array of missions that are critical to its ability to successfully execute its national security mission.¹ Developing fighter pilots requires a significant investment of time and funding. According to Air Force officials, a fighter pilot requires approximately 5 years of training to be qualified to lead flights, at a cost of between about \$3 million to \$11 million depending on the specific type of aircraft.² Retaining qualified pilots is important not only to ensure that operational requirements can be met, but also to recoup the substantial investments the military services make in training their pilots.

Since 2001, we have identified the strategic management of human capital as a high-risk issue because of the mission-critical skills gaps within the federal workforce that pose a high risk to the nation by impeding the government from cost-effectively serving the public and achieving results.³ In 2017, we reported that the military services implemented retention bonuses differently for pilots of different types of aircraft, and that their implementation approaches generally varied from year to year.⁴ We recommended that DOD clarify guidance regarding the extent to which personnel performance should be incorporated into retention decisions—including the use of bonuses to retain pilots. DOD

¹ For the purpose of our review we defined *fighter pilot* as a cockpit pilot of a tactical aircraft, i.e. fixed-wing, jet-powered fighter and attack airplanes. The Army does not operate fighter aircraft. Pilots of unmanned aerial systems were not included in our review.

² These totals do not include the cost of initial training provided to all servicemembers, which involve additional time and costs.

³ GAO, *High Risk Series: Progress on Many High-Risk Areas, While Substantial Efforts Needed on Others*, [GAO-17-317](#) (Washington, D.C.: Feb. 15, 2017).

⁴ GAO, *Military Compensation: Additional Actions Are Needed to Better Manage Special and Incentive Pay Programs*, [GAO-17-39](#) (Washington, D.C.: Feb. 3, 2017).

concurrent with the recommendation, but as of December 2017 had not yet implemented changes in response.

Senate Armed Services Committee Report 114-255, accompanying a bill for the National Defense Authorization Act for Fiscal Year 2017, included a provision for us to review DOD's management of the fighter pilot workforce.⁵ For our report, we (1) assessed the extent to which the military services had differences in the number of fighter pilots compared to authorizations, and described any contributing factors as well as initiatives to address the differences and (2) assessed the extent to which the military services had reevaluated squadron requirements for the number of fighter pilots needed, including consideration of unmanned aerial system (UAS) pilot requirements.

For objective one, we compared "authorizations"—specifically, those positions authorized and funded by Congress for fighter pilots in the active and reserve components of the Air Force, the Navy, and the Marine Corps—with the corresponding staffing levels (i.e., the actual number of pilots available to staff those positions) in those military services.⁶ For each of the military services, we also compared authorizations with staffing levels of all fixed-wing, cockpit-operated communities (hereafter referred to as fixed-wing communities). We did not include the Army in our review because it does not operate fighter aircraft.

For the Air Force and the Marine Corps, we compared fighter pilot staffing levels for the active and reserve components to authorized positions for fiscal years 2006 through 2017,⁷ and we also obtained and analyzed projections for these data for fiscal years 2018 through 2023. We also compared fighter pilot staffing levels for Air Force and Marine Corps

⁵ S. Rep. No. 114-255 (2016)

⁶ The military services periodically review and update the human resources they determine are needed to accomplish specific jobs, workloads, missions and programs, and state those figures (known as "requirements") in staffing documents. Once such a requirement is funded it becomes part of the military service's end strength as an "authorization." The number of authorizations is often smaller than the requirements set out by the military services, and the actual staffing levels of various positions within the military services are often smaller than the number of authorizations.

⁷ Operational positions include flying positions, and certain non-flying positions that directly support combat operations. Non-operational positions are generally non-flying positions, some of which can be filled by other types of military service officers.

active components with operational authorized positions. The Navy does not separate non-operational fighter pilot authorizations from authorizations for other pilots, and therefore we were unable to compare Navy fighter pilot staffing levels with authorizations as we did for the Air Force and the Marine Corps. We instead analyzed staffing levels for Navy fixed-wing communities in the active component for fiscal years 2011 through 2017, and compared pilot staffing levels to authorizations for the three career milestones that Navy officials told us they use to monitor and manage their fixed-wing pilot communities for fiscal years 2013 through 2017. These milestones are first operational tour, mid-career Department Head, and Command. We also analyzed differences between staffing targets and staffing levels for the Navy Reserve fighter pilot community for fiscal year 2017, the only year of data available. We also analyzed Navy retention data for mid-career pilots eligible for Department Head assignments in the same communities for fiscal years 2013 through 2017.⁸

To assess the reliability of the data we obtained, we reviewed corroborating documentation, analyzed the data for inconsistencies, and interviewed service officials about the reliability of the data. We determined that the data were sufficiently reliable to describe the trends in personnel staffing levels and authorizations for the time period included in our scope.

To discuss factors that may have contributed to differences in the number of fighter pilots compared to authorizations, we met with DOD and service officials and reviewed service documentation regarding the factors officials identified. We also held discussion groups with a non-generalizable sample of fighter pilots and squadron leaders to obtain their views on the factors that they believe have contributed to low numbers of fighter pilots. To identify any initiatives the military services had taken or planned to address factors contributing to low numbers of fighter pilots, we interviewed service officials and reviewed documentation related to relevant military service initiatives.

For objective two, we reviewed Air Force, Navy, and Marine Corps guidance to determine the frequency that fighter pilot squadron

⁸ Department Head refers to an operational leadership tour for different aspects of squadron management, including maintenance and squadron operations. Retention data for the Department Head milestone are made available in annual aviation continuation pay reports to Congress. Fiscal year 2018 data will be available in fiscal year 2019.

requirements are to be reviewed. We then reviewed service documentation and interviewed service officials to determine the extent to which these requirements had been reviewed on schedule. We also reviewed service documentation regarding the planned mix of aviation platforms for future operations and discussed with service officials the extent to which these plans are incorporated into forecasts of fighter pilot squadron requirements. Our scope and methodology is described in detail in appendix I.

We conducted this performance audit from November 2016 to April 2018 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

Background

Role of Fighter Pilots

Fighter pilots staff both operational and non-operational positions, and fighter pilots alternate between these positions throughout their career. Operational positions include both flying (i.e., combat pilot or instructor pilot positions) and non-flying positions, such as a close air support duty officer in an Air Operations Center or an air controller in a ground infantry unit. In flying positions, fighter pilots operate aircraft that are critical to achieving and maintaining air dominance during combat operations and include Air Force, Navy, and Marine Corps fixed-wing fighter and attack aircraft with air-to-air, air-to-ground, and electronic warfare missions. These aircraft operate during the first days of a conflict to penetrate enemy air space, defeat air defenses, and achieve air dominance, allowing follow-on ground, air, and naval forces freedom to operate within the battle space. Once air dominance is established, fighter aircraft continue to strike ground targets for the remainder of the conflict. Some fighter aircraft are also essential to protecting the homeland by responding to potential airborne and ground-based threats.

Fighter pilots are assigned a variety of tasks when they are in an operational squadron. As well as studying for flights, flying, and debriefing, fighter pilots must also perform other squadron duties, such as coordinating squadron travel to external training locations, scheduling daily flights, or overseeing squadron maintenance departments. In

addition to these duties, fighter pilots are required to complete common military training (i.e., training that is required for all military personnel and is not linked to a particular occupation). In May 2017, we reported that common military training comprises more than half of mandatory training requirements in the military services (not including additional training that the military services may require for specific groups of servicemembers, such as fighter pilots).⁹

Non-operational positions are generally non-flying positions and include assignments to headquarters or combatant command positions. Certain non-operational positions can only be filled by qualified pilots. For example, certain positions require fighter pilots due to the need for specialized technical knowledge, such as writing operational manuals for fighter aircraft. Other non-operational positions are more general in nature and are divided among officer communities in a military service. For example, Navy officials told us that certain shore assignments—positions that do not involve deployment—can be staffed by officers from aviation, submarine, or surface warfare communities.

Aircraft Operated by Fighter Pilots

DOD's current fighter aircraft fleet is comprised of both legacy and new aircraft (see fig. 1). The legacy aircraft include Air Force F-16, F-15, A-10, and F-22A and Navy and Marine Corps F/A-18A-D, EA-6B, and AV-8B.¹⁰ Most of these aircraft were purchased in the 1970s and 1980s and are more than 25 years old on average. DOD has been recapitalizing this aging legacy fleet by acquiring and fielding new aircraft, namely the Navy's F/A-18E/F and EA-18G and the joint service F-35. The Departments of the Air Force and the Navy are operating many of their fixed-wing aircraft well beyond their original designed service lives, and some of these legacy aircraft are confronted with sustainment challenges that affect their availability. In 2017, senior Air Force and Navy officials testified before the House Armed Services Committee regarding, among

⁹ GAO, *DOD Training: DOD Has Taken Steps to Assess Common Military Training*, [GAO-17-468](#) (Washington, D.C.: May 23, 2017).

¹⁰ In this report, we define "legacy aircraft" as those fixed-wing aircraft that are currently in the operations and support phase of the acquisition lifecycle and generally are no longer in production.

other things, the maintenance and sustainment issues relating to aging aircraft that are affecting the readiness of their forces.¹¹

¹¹ See *The State of the Military*: Hearing before the House Committee on Armed Services, 115th Congress (Feb. 7, 2017) (statements of Admiral William F. Moran, Vice Chief of Naval Operations, and General Stephen W. Wilson, Vice Chief of Staff of the Air Force) and *Aviation Readiness: What's the Flight Plan?*: Hearing Before the Subcommittee on Readiness of the House Committee on Armed Services, 115th Congress (Nov. 9, 2017) (statements of Vice Admiral Troy M. Shoemaker, Commander, Naval Air Forces, and Lieutenant General Steven R. Rudder, Deputy Commandant for Aviation, United States Marine Corps).

Figure 1: Department of Defense Fighter Aircraft



AV-8B Harrier



A-10 Thunderbolt II



EA-6B Prowler



F-15 Eagle



F-16 Fighting Falcon



F/A-18 Hornet



F-22 Raptor



F-35 Lightning II

Source: Defense Video Imagery Distribution System. | GAO-18-113

Note: The graphic does not include aircraft used for training purposes, including aircraft that function as adversaries during air-to-air combat training.

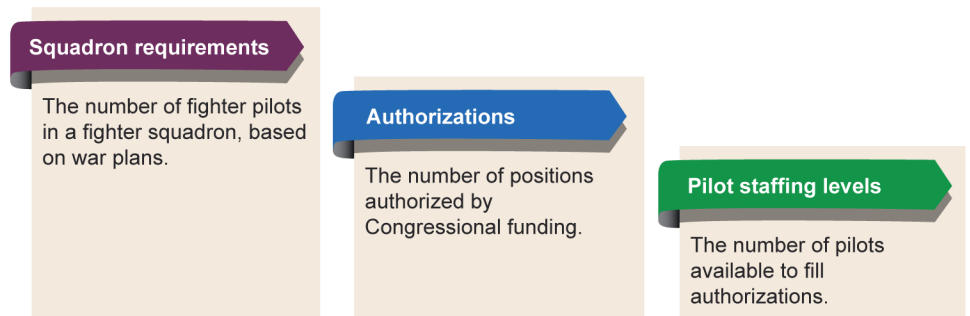
Processes for Determining and Staffing Fighter Pilot Authorizations

According to Air Force, Navy, and Marine Corps guidance, the military services are to determine personnel requirements for military units.¹² Service officials told us that this process includes squadron requirements—that is, the number of operational positions in a fighter pilot squadron that a military service has determined should be staffed by a qualified fighter pilot. Squadron requirements are primarily based on the missions the squadrons are expected to fulfill, and the military services use a variety of inputs to determine fighter pilot squadron requirements. These inputs include the projected operations of fighter squadrons, analyses of the amount of workload in the squadrons, the number of aircraft assigned to the squadrons, and the planned ratio of fighter pilots to aircraft. The military services are to determine the required number of fighter pilots to staff squadrons and meet operational mission needs and to document these in squadron staffing documents.¹³ The military services also determine the rank that pilots should have when staffing specific positions in a squadron—for example, Marine Corps F/A-18 squadron staffing documents specify the rank that should be held by pilots leading specific departments such as those for safety, operations, and maintenance. According to service officials, the military services then staff squadron requirements to the extent possible based on the number of those requirements funded by Congress and the number of trained and qualified personnel available to be staffed to those positions (see fig. 2). We refer to these funded positions as authorizations. Military service workforce planning documents acknowledge that, after this process, a squadron's staffing level may be lower than the established squadron requirements—a readiness risk that the military services manage by assigning a higher priority to the staffing of certain positions, such as those in deployed squadrons.

¹² Air Force Instruction (AFI) 38-201, *Management of Manpower Requirements and Authorizations* (Jan. 30, 2014); Office of the Chief of Naval Operations Instruction (OPNAVINST) 1000.16L, *Navy Total Force Manpower Policies and Procedures* (June 24, 2015); Marine Corps Order (MCO) 5311.1E, *Total Force Structure Process* (Nov. 18, 2015).

¹³ In addition, service officials told us that each of the military services have procedures to determine the number of pilots required to staff non-operational positions, for example in headquarters organizations.

Figure 2: Explanation of Squadron Requirements, Authorizations, and Pilot Staffing Levels



Source: GAO analysis of Department of Defense information. | GAO-18-113

The military services vary in how they define when gaps between authorizations and staffing levels become a shortage. Specifically, fighter pilot staffing levels of 85 to 99 percent of authorizations could be considered a shortage, depending on the military service. For example, Air Force officials told us that their established practice is that pilot communities with less than 100 percent of authorizations are considered to be insufficiently staffed. Navy officials told us that they have a shortage when they are unable to fully staff deploying squadrons. Marine Corps personnel documents reflect that Marine Corps communities with less than 85 percent of authorizations are considered “unhealthy.”

The process of staffing fighter pilots is managed in the Air Force by the Air Force Personnel Center, in the Navy by the Navy Personnel Command, and in the Marine Corps by the Deputy Commandant for Manpower and Reserve Affairs. According to service guidance, the Secretaries are to review squadron requirements, and this review is required every 2 years for the Air Force and the Marine Corps and every 5 years for the Navy.¹⁴ Further, DOD guidance states that staffing requirements are driven by workload and shall be established at the minimum levels necessary to accomplish mission and performance objectives.¹⁵

¹⁴ AFI 38-201; OPNAVINST 1000.16L; OPNAVINST C3501.2L, Mission Areas and Required Operational Capability/Projected Operational Environment Statements (June 30, 2017) (C); MCO 5311.1E.

¹⁵ DOD Directive 1100.4, *Guidance for Manpower Management* (Feb. 12, 2005).

The Military Services Had Fewer Fighter Pilots Than Authorizations Due to a Variety of Contributing Factors; Initiatives Are Underway to Increase Fighter Pilot Staffing Levels

According to Air Force, Navy, and Marine Corps data, each military service had fewer fighter pilots than authorizations from fiscal years 2013 through 2017, and the Air Force and the Marine Corps project that these gaps will continue for several years. According to service officials, because of low numbers of fighter pilots, the military services are unable to staff all operational fighter pilot positions. According to the military services, deploying squadrons have been fully staffed with fighter pilots, due to staffing approaches that include extending deployments and augmenting deployed squadrons with fighter pilots from other squadrons. Service officials identified multiple factors that have led to low numbers of fighter pilots, including challenges in training and retaining fighter pilots. To increase fighter pilot numbers, the military services are taking a variety of actions.

The Air Force, the Navy, and the Marine Corps Had Fewer Fighter Pilots Than Authorizations

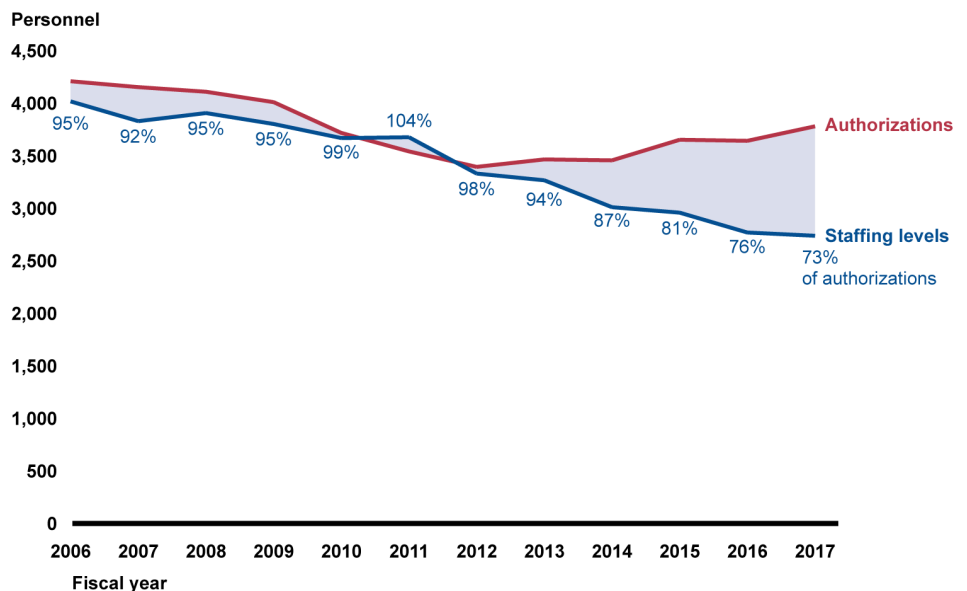
According to Air Force, Navy, and Marine Corps data, each military service had fewer fighter pilots than authorizations (i.e., funded positions) from fiscal years 2013 through 2017.¹⁶ Specifically, the Air Force and the Marine Corps had fewer fighter pilots than authorizations for most years from fiscal years 2006 through 2017. The magnitude of these gaps has grown since fiscal year 2006 and is projected to continue through at least fiscal year 2023. The Navy had fewer fighter pilots than authorizations in fiscal years 2013 through 2017. According to service officials, these gaps between fighter pilot numbers and authorizations have prevented the military services from fully staffing operational positions, including in non-deployed squadrons and training units.

¹⁶ The analysis results presented in this section are for active-duty fighter pilots only. We found that the reserve components in each service also had fewer fighter pilots than authorizations. See appendixes II through IV for a more detailed discussion of pilot staffing levels for both the active and reserve components in the Air Force and the Marine Corps, and the active component of the Navy.

The Air Force Generally Had Fewer Fighter Pilots Than Authorizations Since Fiscal Year 2006, Including for Operational Positions Since Fiscal Year 2014

According to Air Force pilot staffing level and authorizations data for fiscal years 2006 through 2017, the Air Force had fewer fighter pilots than authorizations for 11 of 12 years from fiscal years 2006 through 2017. This gap grew from 192 fighter pilots (5 percent of authorizations) in fiscal year 2006 to 1,005 (27 percent) in fiscal year 2017. According to briefing documents prepared by the Air Force, this gap is concentrated among fighter pilots with fewer than 8 years of experience.¹⁷ The Air Force forecasts that the fighter pilot gap will persist over time, even as the Air Force takes steps to train more fighter pilots and improve retention. Figure 3 shows the Air Force fighter pilot staffing levels and authorizations for fiscal years 2006 through 2017. For information on trends for all Air Force fixed-wing aircraft pilot communities, see appendix II.

Figure 3: Air Force's Active Component Fighter Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017



Source: GAO analysis of Air Force data. | GAO-18-113

¹⁷ Headquarters Air Force (Operations, Plans, and Requirements), *Fighter Enterprise Redesign* (Jan. 10, 2017).

According to Air Force data, the Air Force generally had sufficient fighter pilots to staff operational positions for fighter pilots for fiscal years 2006 through 2013. Air Force officials added that during that period, Air Force fighter pilot gaps were generally limited to non-operational positions, such as staff assignments at Air Force headquarters or combatant commands. However, our analysis found that the Air Force has been unable to fully staff operational positions since fiscal year 2014. The gap between staffing levels and operational positions increased from 39 fighter pilots (1 percent of authorizations) in fiscal year 2014 to 399 (13 percent) in fiscal year 2017.

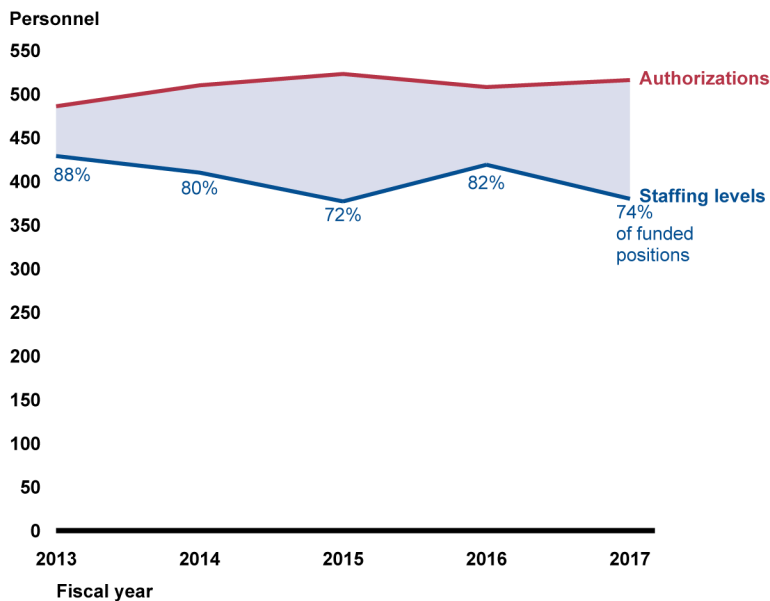
The Navy Had Fewer Fighter Pilots Than Authorizations for Operational Positions in Fiscal Years 2013 through 2017

According to Navy fighter pilot staffing levels and authorizations data for fiscal years 2013 through 2017, the Navy had fewer fighter pilots than authorizations for each of these fiscal years.¹⁸ Specifically, in fiscal year 2013 the Navy had a gap of 57 fighter pilots (12 percent) at the first tour milestone (i.e., a fighter pilot's first operational tour at sea completed between 3 and 6 years of service), and this gap grew to 136 fighter pilots (26 percent) in fiscal year 2017 (see fig. 4).¹⁹ Navy officials told us that they believe current gaps in the fighter pilot community could increase through mid-2019. For information on trends for all Navy fixed-wing aircraft pilot communities, see appendix III.

¹⁸ We were unable to compare Navy data on total authorizations and staffing levels for Navy fighter pilots because, unlike the Air Force and the Marine Corps, the Navy does not fully allocate non-flying assignments to specific communities. As a result, we limited our analysis to comparing authorizations and staffing levels for three career milestones. Further, we were unable to compare the Navy's fighter pilot staffing levels to authorizations for future years because the Navy does not fully allocate future authorizations by pilot community. However, Navy officials provided an aggregate forecast of authorizations for all pilots and projected staffing levels by pilot community through fiscal year 2023.

¹⁹ We report Navy fighter pilot authorizations and staffing levels for the first tour milestone because Navy officials told us that this is the only milestone that cannot be staffed with other types of Naval aviators. We report data for the other two milestones (Department Head and Command) in appendix III.

Figure 4: Navy Fighter Pilot First Operational Tour Actual Staffing Levels Compared with Authorizations, Fiscal Years 2013-2017



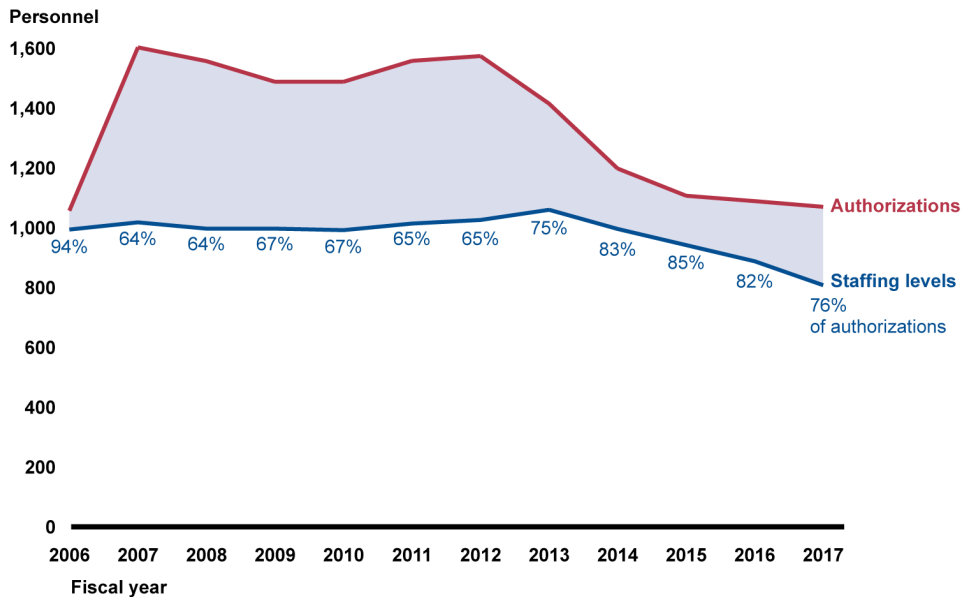
Source: GAO analysis of Navy data. | GAO-18-113

The Marine Corps Had Fewer Fighter Pilots Than Authorizations for Fiscal Years 2006 through 2017, Including for Operational Positions Since Fiscal Year 2016

According to Marine Corps pilot staffing levels and authorizations data for fiscal years 2006 through 2017, the Marine Corps had fewer fighter pilots than authorizations during that time frame. This gap grew from 63 fighter pilots (6 percent of authorizations) in fiscal year 2006 to 262 (24 percent) in fiscal year 2017. Further, according to Marine Corps data, the gap is concentrated in the Marine Corps' junior fighter pilot population (i.e., those fighter pilots below the rank of Officer-4—a major).²⁰ The Marine Corps forecasts that the fighter pilot gap will decrease over time as the Marine Corps phases out legacy aircraft and takes steps to improve retention. Figure 5 shows the Marine Corps active component fighter pilot staffing levels and authorizations for fiscal years 2006 through 2017. For information on trends for all Marine Corps fixed-wing aircraft pilot communities, see appendix IV.

²⁰ The Marine Corps refers to officers between the rank of Officer-1 and Officer-3 as "company grade officers" (i.e., lieutenants and captains), and officers between the rank of Officer-4 and Officer-5 as "field grade officers" (i.e., majors and lieutenant colonels). In this report, we refer to these groups as junior and senior pilots, respectively.

Figure 5: Marine Corps' Active Component Fighter Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017



Source: GAO analysis of Marine Corps data. | GAO-18-113

In addition, Marine Corps data showed that the Marine Corps was unable to fully staff fighter pilot operational positions since fiscal year 2016. The gap between staffing levels and operational positions increased from 12 fighter pilots (1 percent of authorizations) to 57 (7 percent) in fiscal years 2016 through 2017.

The Military Services Used Various Staffing Approaches to Mitigate the Impact of Low Numbers of Fighter Pilots on Deploying Squadrons

Although all of the military services had fewer fighter pilots than authorizations in fiscal years 2013 through 2017, service officials stated that deploying squadrons have been fully staffed with fighter pilots. Service officials reported using various approaches to continue to fully staff deploying fighter squadrons, including (1) prioritizing staffing fighter pilots to flying positions that require fighter pilot-specific technical skills; (2) using senior pilots to staff junior positions; and (3) having pilots deploy for longer and more frequently than planned, including on deployments

with other squadrons.²¹ For example, Navy officials told us that approaches such as extending fighter pilots' deployments allowed them to reduce the fiscal year 2017 first tour fighter pilot gap from 136 pilots (26 percent) to 75 pilots (15 percent).

However, squadron leaders and fighter pilots told us that these approaches are having a negative impact on the fighter pilot workforce. Specifically, squadron leaders and fighter pilots told us that the high pace of operations for senior fighter pilots has limited their availability to train junior pilots, which has constrained the military services' ability to increase the number of pilots with specific qualifications. In addition, fighter pilots told us that increased frequency of individual deployments cause instability for their families and lead to career dissatisfaction. Additionally, as we have previously reported, a high tempo of operations has increased the challenge of aviation squadrons to rebuild readiness. For example, according to Air Force officials, high deployment rates for Air Force squadrons have resulted in less time for squadrons to complete their full training requirements because high deployment rates mean that there are fewer aircraft available for training at home stations.²²

Service officials report that they can also mitigate low numbers of fighter pilots by leveraging surpluses in other pilot communities. For example, as outlined in Air Force documents supporting pilot retention bonuses, the Air Force has staffed mobility pilots (i.e., cargo transport and aerial refueling pilots) to instructor pilot positions for certain basic flying training that would otherwise be staffed by fighter pilots. The Navy can also staff certain Department Head positions designated for fighter pilots with non-pilot aviators from that community.²³ According to military service data, fighter pilot communities generally have the largest gaps among all military fixed-wing pilot communities. For example, in fiscal year 2017 the Air Force had 73 percent of the fighter pilots it needed, while the bomber

²¹ In 1999, we reported that the military services had similar challenges meeting authorizations for all pilots—not just fighter pilots—and were using similar staffing approaches to meet authorizations. We recommended that DOD reassess requirements and consider using non-pilot personnel to staff non-operational positions. DOD partially concurred with the recommendation, and the Air Force implemented it by using personnel other than active duty pilots to staff pilot positions.

²² GAO, *Military Readiness: DOD's Readiness Rebuilding Efforts May Be at Risk without a Comprehensive Plan*, [GAO-16-841](#) (Washington, D.C.: September 7, 2016).

²³ The Navy refers to non-pilot aviators as Naval Flight Officers. These officers are responsible for navigation or weapon systems on cockpit-operated aircraft.

community, which had the second largest gap among Air Force fixed-wing pilot communities, had 85 percent of the pilots it needed.

Service Officials Cited Multiple Factors That Have Contributed to Low Numbers of Fighter Pilots

According to service officials, squadron leaders, and fighter pilots, multiple inter-related factors have reduced each military service's number of fighter pilots. Factors cited include reductions to active duty end strength, aircraft readiness challenges, and declining retention.

Reductions to Active Duty Military End Strength

Reductions to active duty military end strength have contributed to reductions in fighter pilot staffing levels. Service officials told us that reductions to military service end strength targets as part of the 2008 drawdown of forces in Iraq and Afghanistan and funding reductions related to the Budget Control Act of 2011 led to reductions in the fighter pilot workforce.²⁴ For example, the Air Force offered 54 fighter pilots early retirement incentives in fiscal years 2014 through 2015, while the Marine Corps offered 49 fighter pilots early retirement options between fiscal years 2013 through 2016. Further, as we have previously reported, the Air Force used fighter pilots to meet the initial demand for UAS operators.²⁵ Air Force officials told us that they removed 206 of those pilots from the fighter pilot community in fiscal years 2011 through 2012. Reduced force structure has also decreased the opportunities for fighter pilots to gain experience in their aircraft. For example, the Air Force reported that the number of total Air Force fighter squadrons (including the reserve components) declined from 134 in fiscal year 1989 to 55 in fiscal year 2017 (a 59-percent decrease), and as such fewer squadrons are available to provide newly trained fighter pilots with flying experience.

²⁴ For example, active duty end strength decreased from 1.4 million enlisted and officer personnel in fiscal year 2012 to 1.3 million requested in fiscal year 2018 (a 6-percent decrease). The Budget Control Act of 2011, Pub. L. No. 112-25 (2011), established, among other things, a congressional Joint Select Committee on Deficit Reduction to propose legislation that would reduce federal deficits by \$1.5 trillion over 10 years (fiscal years 2012–2021), and two sequestration procedures: a sequestration procedure originally to be ordered by the President on January 1, 2013, to ensure that the level of deficit reduction would be achieved in the event that the Joint Committee failed to reach agreement to reduce the deficit by at least \$1.2 trillion, and an additional sequestration procedure triggered if appropriations exceed established discretionary spending caps in a given fiscal year in fiscal years 2012 through 2021. The sequestration in fiscal year 2013 used the former procedure, triggered because the Joint Committee did not reach agreement.

²⁵ GAO, *Air Force: Actions Needed to Strengthen Management of Unmanned Aerial System Pilots*, [GAO-14-316](#) (Washington, D.C.: Apr. 10, 2014).

Aircraft Readiness Challenges

Reduced aircraft availability has affected fighter pilots' ability to meet flight hour targets. Service leaders told us that this has resulted in delays in training new pilots with the necessary qualifications to participate in certain missions. Specifically, according to November 2017 testimony, Air Force, Navy, and Marine Corps leaders reported that fighter pilots do not meet military service flight hour targets—in part due to reduced aircraft availability. For example, Navy and Marine Corps leaders testified that Navy and Marine Corps F/A-18 pilots average 13.5 and 12.7 flight hours per month, respectively, compared with goals of 20.1 and 15.7 hours per month.²⁶ A senior Air Force leader testified before Congress that Air Force fighter pilots average about 16 flight hours per month.²⁷ In June 2017 we reported on readiness challenges in Air Force and Marine Corps aviation squadrons.²⁸

The military services have trained fewer fighter pilots than targeted over the last decade. In fiscal years 2007 through 2016, the Air Force trained 12 percent fewer new fighter pilots than the targeted amount, while the Navy and the Marine Corps each trained 8 percent fewer new fighter pilots than the targeted amount.²⁹ Fighter pilots told us that the need to prioritize the staffing of experienced pilots to deploying squadrons has limited the number of experienced personnel available to train newer pilots at home stations.

Reduced aircraft readiness has further limited fighter pilot training. Squadron leaders told us that longer maintenance of legacy aircraft reduces the availability of those aircraft for training, leading to insufficient

²⁶ *Aviation Readiness: What's the Flight Plan?*: Hearing Before the House Committee on Armed Services (Readiness Subcommittee), 115th Congress (Nov. 9, 2017) (statements of Vice Admiral Troy M. Shoemaker, Commander, Naval Air Forces, United States Navy; and Lieutenant General Steven R. Rudder, Deputy Commandant for Aviation, United States Marine Corps).

²⁷ *Aviation Readiness: What's the Flight Plan?*: Hearing Before the House Committee on Armed Services (Readiness Subcommittee), 115th Congress (Nov. 9, 2017) (statement of Lieutenant General Mark C. Nowland, Deputy Chief of Staff for Operations, United States Air Force). Air Force officials told us that there is no associated flight hour target. Instead, Air Force readiness metrics focus on the number of sorties flown by pilots.

²⁸ GAO, *Department of Defense: Actions Needed to Address Five Key Mission Challenges*, [GAO-17-369](#) (Washington, D.C.: June 13, 2017).

²⁹ Air Force training data include reserve component pilots.

Recent Safety Concerns Regarding Onboard Systems in Naval Aircraft

In April 2017, the Navy paused all basic flight training on the T-45 aircraft due to safety concerns regarding the oxygen supply and atmospheric pressurization systems aboard the training aircraft. The Navy and the Marine Corps share basic flight training resources, including training for fixed-wing aircraft pilots on T-45 aircraft. Navy and Marine Corps officials told us that if these basic training squadrons are unable to produce newly trained fighter pilots on schedule, this can lead to a decreased number of new fighter pilots in both military services. The F/A-18 has also been affected by problems with onboard oxygen supply systems leading to hypoxia, which can occur when aircrews receive insufficient or contaminated oxygen on board the aircraft. In August 2017 the Navy established a team to lead its effort to research and prevent these problems in fixed-wing aircraft.

Source: GAO analysis of Navy and Marine Corps information.
I GAO-18-113

numbers of trained pilots. In addition, aircraft readiness challenges led the Navy to pause flight training on the T-45 training aircraft in April 2017 due to safety concerns regarding the oxygen supply systems aboard the training aircraft. Navy officials reported that gaps in first tour operational positions designated for all fixed-wing aircraft pilot communities could grow from 86 pilots in fiscal year 2017 to about 100 in fiscal year 2019.

Fighter Pilot Retention Challenges

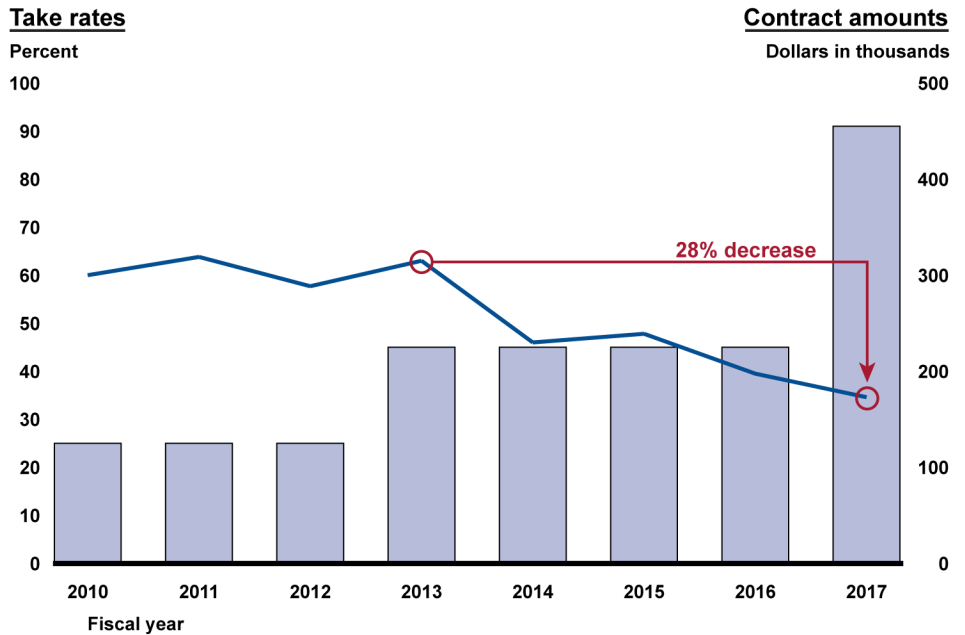
Declining retention has also contributed to low fighter pilot numbers. Our analysis of Air Force and Navy bonus retention data shows that retention of experienced fighter pilots has declined in recent years.³⁰

We found that the number of Air Force fighter pilots that have signed retention contracts decreased from 63 percent in fiscal year 2013 to 35 percent in fiscal year 2017 (see fig. 6). This decline has continued even as the Air Force increased its maximum aviation bonus contract from \$125,000 in fiscal year 2012 to \$225,000 beginning in fiscal year 2013, the highest amount offered by any of the military services.³¹

³⁰ Unlike the Air Force and the Navy, the Marine Corps did not offer bonus retention contracts between fiscal years 2012 and 2017. Accordingly, we only present Air Force and Navy bonus retention contract data for those years.

³¹ In fiscal year 2017, the Air Force increased the maximum aviation bonus contract to \$455,000—13-year contracts at \$35,000 per year.

Figure 6: Air Force Fighter Pilot Retention Bonus Take Rate and Maximum Contract Amounts Offered, Fiscal Years 2010-2017



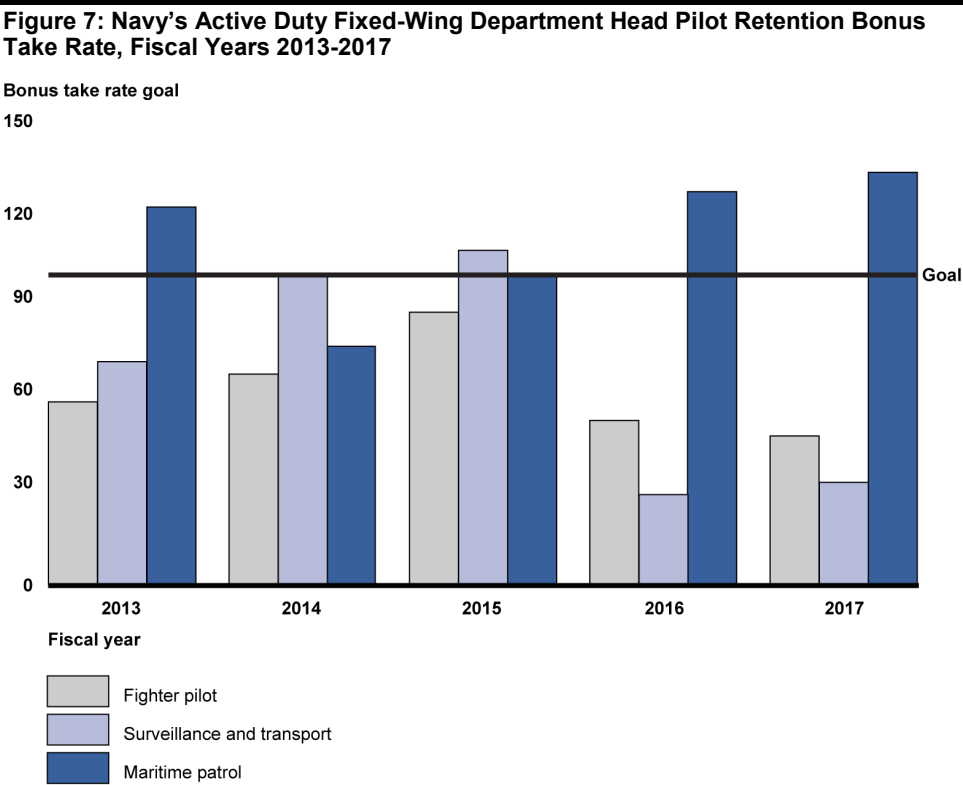
Source: GAO analysis of Air Force data. | GAO-18-113

According to Navy retention data, the Navy pool of fighter pilots eligible for the Department Head milestone (i.e., a mid-career operational leadership tour for different aspects of squadron management for pilots with between about 11 and 13 years of service) has shrunk over time. Navy officials told us that, as a result, the percentage of fighter pilots selected for the Department Head milestone has increased. For example, the Department Head selection rate for Navy F/A-18 pilots increased from 49 percent in fiscal year 2012 to 100 percent in fiscal year 2017.

Further, the Navy did not meet its goals for fighter pilots signing retention bonuses at the Department Head milestone in fiscal years 2013 through 2017.³² For example, the Navy fell short of its retention bonus target of 73 fighter pilots by 38 pilots (48 percent of the target) for fiscal year 2017. In comparison, the surveillance and transport pilot community met or exceeded its target of pilots who signed a bonus contract 2 out of 5 years

³² Retention data for the Department Head milestone are made available in annual aviation continuation pay reports to Congress. Fiscal year 2018 data will be available in fiscal year 2019.

during that same period, while the maritime patrol pilot community met or exceeded its target 4 out of 5 years. Figure 7 shows the Navy Department Head active component fixed-wing pilot retention bonus take rate for fiscal years 2013 through 2017.



Source: GAO analysis of Navy data. | GAO-18-113

Squadron leaders and fighter pilots we met with attributed declining retention to the staffing approaches being used by the military services to mitigate fighter pilot gaps and fully staff deployed squadrons. For example, squadron leaders told us that assigning senior fighter pilots to junior positions hurts retention by reducing leadership opportunities believed to be necessary for promotion. Fighter pilots also told us that quality of life has decreased as a result of longer and more frequent deployments. Further, fighter pilots told us that understaffing fighter pilots in operational units has resulted in an increased workload per pilot and lower quality of service for non-deployed fighter pilots in those units.

The Air Force Has Implemented Initiatives to Help Increase Fighter Pilot Numbers and the Navy and the Marine Corps Are Formulating Initiatives to Address Overall Retention Concerns

The Air Force has developed and implemented initiatives to help increase fighter pilot numbers, and the Navy and the Marine Corps are developing initiatives to address overall retention concerns. The Air Force established a dedicated team to identify and develop initiatives specifically to address its reported fighter pilot shortage, and this effort has resulted in over 35 implemented initiatives. The Navy and the Marine Corps have not formulated initiatives specifically for fighter pilots, but have identified actions to address retention concerns. Navy and Marine Corps officials stated that, because the military services can still staff authorizations for deployed squadrons, they do not believe their staffing levels of fighter pilots have reached a critical shortage. However, Navy and Marine Corps personnel management officials we met with told us that they are closely monitoring trends in fighter pilot retention, and they believe that decreased retention in the near future may exacerbate fighter pilot gaps in their military services. The military services' initiatives are summarized below.

- The Air Force established a dedicated effort to address fighter pilot workforce challenges, and many initiatives from this effort have been implemented. Specifically, in March 2016, the Chief of Staff of the Air Force directed the initiation of an effort to address the Air Force fighter pilot shortage. The Air Force created a Fighter Enterprise Tiger Team in March 2016, and began formulating initiatives to address the fighter pilot shortage that the Air Force identified. For example, as the result of one initiative, 126 contractors have been placed in fighter squadrons to assist with administrative tasks and reduce workload for fighter pilots, and additional contractor support is in the process of being added. Also, in the fall of 2016 the Air Force reinstated its award program to recognize fighter pilots for superior performance. According to a member of the Air Force's Fighter Enterprise Tiger Team, the awards are non-monetary, but because they are merit-based they can help fighter pilots to be more competitive when being assessed for promotion.

In February 2017, the Air Force effort was expanded from a focus on fighter pilots to include all rated personnel and renamed the Aircrew Crisis Task Force.³³ The 37 initiatives implemented by the Air Force as of November 2017 as a result of the Fighter Enterprise Tiger Team and Aircrew Crisis Task Force efforts are presented in appendix V.

³³ Rated personnel are servicemembers with an aeronautical rating including pilots, combat systems officers, and air battle managers.

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- The Navy is formulating a service-wide strategy—referred to as Sailor 2025—which includes over 40 initiatives to address retention issues throughout the Navy. We identified 10 initiatives from Sailor 2025 that may address some of the retention issues raised in our discussion groups with fighter pilots—such as dissatisfaction with the assignments and promotion processes. For example, Navy officials told us they are developing staffing software to manage assignments and make the process more transparent and flexible. The Navy is also testing a new performance evaluation system to more accurately evaluate sailor performance. In addition, the Navy has adjusted the existing aviation bonus program by increasing the maximum bonus amount for fighter pilots from \$25,000 to \$30,000 per year for fiscal year 2018.³⁴ To increase the number of available fighter aircraft, the Navy has also established a Rhino Readiness Recovery team—referring to the Navy’s term for the F/A-18 E-F Super Hornet aircraft—to identify and address readiness challenges in that community. Navy officials told us they believe their approaches are sufficient to address any potential future Navy fighter pilot gaps.
 - In November 2017, the Marine Corps reinstated the aviation bonus program last offered by the Marine Corps in fiscal year 2011. The Marine Corps is offering 2-year contracts totaling \$40,000 to fighter pilots who have completed their service obligation—except for those fighter pilots assigned to the EA-6B aircraft. However, the Marine Corps is not in the process of developing any non-monetary initiatives to address pilot retention. Rather, the Marine Corps is addressing aircraft readiness challenges—an issue consistently raised by fighter pilots in our discussion groups—by establishing four lines of effort to increase the number of available fighter aircraft for fighter squadrons. Marine Corps officials told us that they have begun implementing multiple initiatives for those lines of effort. For example, one initiative is focused on improving availability of aircraft spare parts by increasing their funding and modernizing the spare parts supply chain. Another initiative is focused on growing the maintenance workforce and retaining experienced aircraft maintainers. Specifically, the Marine Corps is offering retention bonuses to experienced aircraft maintainers.

³⁴ This amount is less than the maximum authorized by Congress and significantly less than the amounts in bonus contracts offered by the Air Force.

The Military Services Have Not Reevaluated Fighter Pilot Squadron Requirements to Reflect Changing Conditions, Increased Workload, and Emerging UAS Requirements

Fighter pilots and squadron leaders told us that the fighter pilot occupation has significantly changed in recent years, but the military services have not reevaluated fighter squadron requirements. Fighter pilots and squadron leaders from each of the military services consistently told us that the fighter pilot occupation has significantly changed in recent years due to changes in fighter aircraft tactics and technology, additional training requirements, and the removal of administrative support positions from squadrons. The fighter pilots added that these changes have led to an unsustainable increase in workload. As discussed earlier, squadron requirements—the number of fighter pilots needed to meet operational mission needs—are calculated by the military services using a variety of inputs, including workload. Once these requirements are funded by Congress, they are an “authorization.” Service guidance requires squadron requirements to be reevaluated on a 2-year schedule (5 years for the Navy) and to be updated as conditions change.³⁵

For the Air Force, guidance defines staffing requirements as the staffing needed to accomplish a job, mission, or program, and notes that staffing should be sized to reflect the minimum essential level to accomplish the required workload.³⁶ The Office of the Administrative Assistant to the Secretary of the Air Force (Resources), along with Major Command manpower staffs establish staffing standards and, at a minimum, by policy are to reevaluate these standards for applicability and updates every 2 years, or earlier if dictated by significant workload or mission changes. The Air Force Manpower Analysis Agency determines staffing resource requirements and provides staffing and management consultation services to Air Force functional communities for improved resource utilization and enhanced mission effectiveness and efficiency.³⁷

The Air Force could not provide specifics on the most recent updates to squadron requirements, because such data were stored in a database that managed requirements on a position-by-position basis, rather than aggregated by squadron. Air Force pilots and squadron leaders consistently told us that changing conditions in fighter squadrons, such as a higher pace of changes to tactics and technology, increased training

³⁵ AFI 38-201; OPNAVINST C3501.2L (C); MCO 5311.1E.

³⁶ AFI 38-201.

³⁷ Air Force Mission Directive 41, *Air Force Manpower Analysis Agency (AFMAA)* (July 23, 2016).

requirements, and reduced administrative support, have increased fighter pilot workload. However, Air Force officials told us that metrics that inform squadron requirements (i.e., crew ratios, the targeted ratio of pilots to aircraft) have not been increased because the Air Force is instead prioritizing the effort to recapitalize its fleet of fighter aircraft. Separately from reevaluating squadron requirements, Air Force officials told us that they have implemented changes to address workload concerns cited by fighter pilots—such as adding contractor staff in squadrons to provide administrative support, as part of initiatives to address fighter pilot shortages they have identified. According to Air Force officials, the Air Force is currently reassessing non-operational requirements for fighter pilots (i.e., non-flying positions at headquarters organizations). Air Force officials told us that this reassessment is focused on determining which non-operational requirements currently assigned to fighter pilots could be assigned to other types of officers or pilots, to reduce the overall number of fighter pilot requirements.

For the Navy, squadron requirements are dependent on the current wartime requirements developed by the Navy, referred to as the *Required Operational Capability and Projected Operational Environment* of a particular squadron, aircraft configuration, specified operating profile, computed workload, and established doctrinal constraints.³⁸ The June 2017 update to the relevant Navy guidance reduced the frequency of the reviews of these requirements from every 2 years to every 5 years, with updates as required by those officials responsible for specific units.³⁹

Navy officials told us that reviews are to be completed every 2 years, but updates are only made to squadron staffing documents if specific events occur, such as additional aircraft being assigned to a squadron. Navy officials added that they believe squadron requirements are accurate and updated with sufficient frequency. However, Navy pilots and squadron leaders consistently told us that changing conditions in fighter squadrons, such as a higher pace of changes to tactics and technology, increased training requirements, and more frequent individual deployments, have increased fighter pilot workload. However, the Navy has not recently updated squadron requirements to reflect such changes. Specifically, Navy fighter pilot squadron requirements are outlined in 15 Navy

³⁸ OPNAVINST 1000.16L.

³⁹ OPNAVINST C3501.2L (C).

squadron staffing documents, and as of November 2017, 9 out of 15 of those documents had not been updated within the last 2 years.

For the Marine Corps, guidance states that reviews to optimize force structure will be conducted every 2 years, taking into consideration new and emerging requirements.⁴⁰ Marine Corps pilots and squadron leaders consistently told us that changing conditions in fighter squadrons, such as a higher pace of changes to tactics and technology, reduced aircraft availability, and more frequent individual deployments, have increased fighter pilot workload. However, the Marine Corps has not updated squadron requirements to reflect such changes. Specifically, Marine Corps fighter pilot squadron requirements are outlined in four fighter squadron staffing documents, and, as of November 2017, none had been updated within the last 2 years.

Marine Corps squadron leaders and fighter pilots told us that updates to squadron requirements are not being conducted for squadrons of legacy aircraft, but added that they believe updates are warranted due to the continued delays in fielding the F-35 and resulting extensions to the planned service of legacy platforms. Marine Corps officials told us that they have not updated squadron requirements because (1) Marine Corps fighter pilot authorizations and staffing levels are below squadron requirements, so any increase to squadron requirements would require a significant increase to fighter pilot authorizations, and (2) the Marine Corps has faced challenges obtaining technical assistance to conduct workload assessments in fighter squadrons. The Navy Manpower Analysis Center conducts workload reviews of squadrons, based on specific events such as changes to the amount of time needed for maintaining the specific type of aircraft. Navy and Marine Corps fighter pilots we met with told us that they have had difficulties maintaining fighter jets in their squadrons, and Navy and Marine Corps leaders have made similar statements in congressional testimony.⁴¹ Further, Marine Corps officials told us that they have had difficulty utilizing the Navy Manpower Analysis Center to update workload analyses for their fighter squadrons, as they believed the center prioritizes work for Navy

⁴⁰ MCO 5311.1E.

⁴¹ *Aviation Readiness: What's the Flight Plan?*; Hearing before the Subcommittee on Readiness of the House Committee on Armed Services, 115th Cong. (Nov. 9, 2017) (statements of Vice Admiral Mike Shoemaker, Commander, Naval Air Forces, and Lieutenant General Steven Rudder, Deputy Commandant for Aviation, United States Marine Corps).

organizations. Navy Manpower Analysis Center officials told us that there is no formal requirement for their organization to conduct analyses for the Marine Corps, but that they respond to such requests on an ad-hoc basis. They added that the Marine Corps Combat Development Command has formal responsibility for updating Marine Corps workload analyses. We have previously reported that the size and data collection capacity of the Navy Manpower Analysis Center has limited the Navy's capacity to carry out periodic workload reassessments, which may be a contributing factor to chronic under-staffing of ship crews.⁴²

The Military Services Have Not Incorporated Plans for Increased Reliance on UAS into Fighter Pilot Workforce Projections

According to a DOD planning document, funding for UAS platforms was expected to grow by 17 percent in fiscal years 2014 through 2018.⁴³ Moreover, in 2015, the Secretary of the Navy directed the establishment of a Deputy Assistant Secretary of the Navy for Unmanned Systems⁴⁴ and announced that the F-35 will likely be the last cockpit-operated strike fighter aircraft the Department of the Navy will buy or fly.⁴⁵ The Chief of Naval Operations announced in 2017 that the future of the Navy includes UAS systems as an integral part of the future fleet and must be purchased in large numbers to expand naval presence in key areas.⁴⁶ For example, the Navy is developing a UAS platform—the MQ-25 Stingray—which is intended to replace that portion of the F/A-18 fighter aircraft's mission set that involves re-fueling other F/A-18 aircraft.

Also, in 2015 the Secretary of the Air Force stated that UAS pilots were flying on average about four times more hours than pilots in cockpit-operated aircraft.⁴⁷ Further, a document outlining the Air Force's vision for UAS for fiscal years 2009 through 2047 notes that systems will work in

⁴² GAO, *Navy Force Structure: Actions Needed to Ensure Proper Size and Composition of Ship Crews*, [GAO-17-413](#) (Washington, D.C.: May 18, 2017).

⁴³ Department of Defense, *Unmanned Systems Integrated Roadmap FY2013-2038* (January 2014).

⁴⁴ Secretary of the Navy Memorandum, *Treat Unmanned as Unmanned* (Nov. 13, 2015).

⁴⁵ Prepared remarks of Ray Mabus, Secretary of the Navy, for the Sea-Air-Space Exposition (Apr. 15, 2015).

⁴⁶ Admiral John Richardson, Chief of Naval Operations White Paper, *The Future Navy* (May 17, 2017).

⁴⁷ Deborah Lee James, Secretary of the Air Force, *State of the Air Force Press Briefing* (Jan. 15, 2015).

tandem with cockpit-operated aircraft, for example to attack air-defense systems, and that autonomous technologies will potentially allow one pilot to direct multiple aircraft, leading to personnel efficiencies.⁴⁸

Although the impact of UAS on the fighter pilot workforce appears to be significant, the Air Force, the Navy, and the Marine Corps have not accounted for the planned increased use of UAS to complete missions similar to those carried out by fighter aircraft, and the potential impact of these changes on fighter pilot requirements. Specifically, Air Force and Navy officials told us that their military services have not conducted an assessment of the impact of future UAS operations on fighter pilot requirements.⁴⁹ While the UAS platforms that are expected to overlap with fighter aircraft missions will not be fielded until the mid-2020s, the length of time required to develop an experienced fighter pilot compels the military services to begin incorporating these planned changes to fighter pilot requirements promptly. For example, Navy fighter pilots who are entering initial training in 2018 will not have completed their active duty service obligation (currently 8 years after Navy pilots complete flight training) when the MQ-25 Stingray system is expected to be fielded in 2026.

A key tenet of human capital planning is determining existing and future skills and competencies, and associated workforce gaps.⁵⁰ Without steps by the military services, to include reevaluating workload and taking into account the impact that the planned use of UAS will have on the fighter pilot workforce, the military services will not fully know the extent and

⁴⁸ United States Air Force, *Unmanned Aircraft Systems Flight Plan 2009-2047* (May 18, 2009).

⁴⁹ According to Marine Corps officials, the Marine Corps uses enlisted personnel to operate UAS.

⁵⁰ GAO, *Human Capital: Key Principles for Effective Strategic Workforce Planning*, [GAO-04-39](#) (Washington, D.C.: Dec. 11, 2003). To identify strategic workforce planning principles, we reviewed our own guidance, reports, and testimonies on federal agencies' workforce planning and human capital management efforts and guidance available from leading human capital periodicals, such as the *Workforce Planning Resource Guide for Public Sector Human Resource Professionals*. We also met with officials from organizations with government-wide responsibilities for or expertise in workforce planning, such as the Office of Personnel Management and the National Academy of Public Administration, to identify additional guidance. We synthesized the information we collected and derived principles that appeared most important to effective strategic workforce planning.

nature of gaps between fighter pilot numbers and authorizations and how to best target actions to address these gaps.

Conclusions

Fighter pilots are critical to achieving and maintaining air dominance during combat operations. To achieve that mission, the military services must have appropriate numbers of qualified fighter pilots. Service officials report that no unit is deploying without 100 percent of its fighter pilots, and they believe that they will continue to be able to meet their operational missions. Nevertheless, the Air Force, the Navy, and the Marine Corps, are reporting fewer fighter pilots than authorizations, and they project that these gaps will continue through at least fiscal year 2023. Without re-evaluating fighter pilot requirements, it will be difficult for the military services to accurately determine the number of fighter pilots needed to complete missions and help ensure success in combat. Specifically, without updating squadron requirements to reflect the growing administrative burden on fighter pilots in non-deployed squadrons, the currently identified differences between fighter pilot numbers and authorizations may be understated. By contrast, without updating future fighter pilot requirements to take into account changing roles and missions—in particular the increasing role of UAS in combat operations—forecasted fighter pilot gaps may be overstated. In short, reevaluating fighter pilot requirements is a key first step to help the military services clearly determine the magnitude of the gaps and target strategies to meet their personnel needs.

Recommendations for Executive Action

We are making the following three recommendations:

- The Secretary of the Air Force should ensure that the Director of Operations and the Air Force Manpower Analysis Agency reevaluate fighter pilot squadron requirements, to include updating current assumptions of fighter pilot workload, and assessing the impact of future incorporation of UAS platforms into combat aviation. (Recommendation 1)
- The Secretary of the Navy should ensure that the Chief of Naval Operations reevaluate fighter pilot squadron requirements, to include updating current assumptions of fighter pilot workload, and assessing the impact of future incorporation of UAS platforms into combat aviation. (Recommendation 2)

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- The Secretary of the Navy should ensure that the Commandant of the Marine Corps and the Deputy Commandant for Aviation reevaluate fighter pilot squadron requirements. (Recommendation 3)

Agency Comments

We provided a draft of this report to DOD for review and comment. We had initially recommended that the Marine Corps also assess the impact of UAS platforms on fighter pilot squadron requirements, but removed that portion of the third recommendation because Marine Corps officials told us that Marine Corps UAS squadrons will continue to be resourced with operators through the accession process and Marine Corps UAS operator requirements do not affect either pilot inventories or fighter pilot workload. In its written comments, reproduced in appendix VI, DOD concurred with our recommendations, citing its commitment to addressing manpower, personnel, and training challenges for the fighter pilot community and broader aviation and aviation support capabilities. DOD also provided technical comments, which we incorporated as appropriate.

We are sending copies of this report to appropriate congressional committees; the Secretary of Defense; the Secretary of the Air Force; the Secretary of the Navy; and the Commandant of the Marine Corps. In addition, the report will be available at no charge on the GAO website at <http://www.gao.gov>.

If you or your staff have any questions about this report, please contact Brenda S. Farrell at (202) 512-3604 or farrellb@gao.gov. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix VII.



Brenda S. Farrell
Director, Defense Capabilities and Management

Appendix I: Scope and Methodology

To assess the extent to which the military services had differences in the number of fighter pilots compared to authorizations, as well as contributing factors and service initiatives to address the differences, we obtained and analyzed data on authorizations designated for pilots and corresponding staffing levels of pilots for all fixed-wing, cockpit-operated (hereafter referred to as fixed-wing) aircraft communities in the Air Force, the Navy, and the Marine Corps. We did not include the Army in the scope of our review because the Army does not operate fighter aircraft.

For the Air Force and the Marine Corps active component, we compared pilot staffing levels with authorizations for all fixed-wing aircraft communities for fiscal years 2006 through 2017.¹ We obtained and analyzed projected authorizations and staffing levels for the same pilot communities for fiscal years 2018 through 2023. We further obtained and reviewed Marine Corps data on fighter pilot operational position staffing targets and staffing levels for fiscal year 2017 and similar Air Force data for fiscal year 2018. We also compared Air Force and Marine Corps reserve component fighter pilot staffing levels with authorizations for fiscal years 2006 through 2017.

For the Navy, we obtained and analyzed data on authorizations designated for active and reserve component pilots for fiscal years 2006 through 2017, and staffing levels for all Navy fixed-wing aircraft communities in the active component for fiscal years 2011 through 2017. However, the Navy's authorization data did not specify how many fighter pilots were assigned to non-flying assignments because the Navy does not fully assign non-flying authorizations to specific communities, unlike the Air Force and the Marine Corps. Therefore, we were unable to conduct an analysis comparing total Navy fighter pilot staffing levels with authorizations, as we did for the Air Force and the Marine Corps. We instead obtained and analyzed Navy data on differences between authorizations and pilot staffing levels for first operational tour, Department Head, and Command positions for all fixed-wing aircraft pilot communities in the active component. We also obtained and analyzed Navy data on differences between staffing targets and pilot staffing levels for the Navy Reserve for fiscal year 2017, the only year of data available. We also obtained and analyzed Navy retention data for pilots eligible for

¹ Authorizations include both operational and non-operational positions. Operational positions include flying positions and certain non-flying positions that directly support combat operations. Non-operational positions are generally non-flying positions, some of which can be filled by other types of military service officers.

Department Head assignments, a mid-career milestone in fixed-wing communities for fiscal years 2011 through 2017. Retention data for the Department Head milestone are made available in annual aviation continuation pay reports to Congress. Fiscal year 2018 retention data will be available in fiscal year 2019. We further obtained and analyzed the number of fighter pilots the Air Force, the Navy, and the Marine Corps trained in fiscal years 2007 through 2016.

To assess the reliability of the data we obtained, we reviewed corroborating documentation, analyzed the data for inconsistencies, and interviewed service officials about the reliability of the data. We determined that the data we used were sufficiently reliable to describe the trends in personnel staffing levels and authorizations for the time period included in our scope.

We met with DOD and service officials to discuss the results of our analysis and factors that may have contributed to low numbers of fighter pilots. We also collected and reviewed service documentation regarding the factors they identified. We interviewed service officials and reviewed documentation to identify any initiatives taken or planned to increase fighter pilot numbers.

In addition, we selected a non-generalizable sample of locations where fighter pilots are stationed (see table 1). We selected these locations based on geographic diversity (one location for each military service in both the eastern and western portions of the contiguous United States), a diversity of types of fighter aircraft, and a mix of squadron types at the locations (i.e., operational squadrons, training squadrons, and reserve component squadrons). In selecting locations we also considered the availability of pilots due to conflicts with deployment or training events. At each location, we moderated one to two discussion groups with fighter pilots for a total of 13 discussion groups ranging from between 3 and 20 pilots per group. We held separate sessions with junior and senior pilots at all locations, except for at Naval Air Station Oceana, Marine Corps Air Station Cherry Point, and Marine Corps Air Station Miramar, due to pilot availability. We also interviewed unit leadership at these locations (i.e., wing and squadron commanders and executive officers) to obtain their perspective on the status of the fighter pilot workforce. While these discussion groups and interviews allowed us to learn about many important aspects of the fighter pilot workforce from the perspective of fighter pilots and squadron leaders, they were designed to provide anecdotal information and not results that would be representative of all the department's more than 5,000 fighter pilots as of fiscal year 2017.

Table 1: Locations Visited for Fighter Pilot Discussion Groups

Military service	Installation	Location	Aircraft type
Air Force ^a	Holloman AFB	Alamogordo, NM	F-16 Fighting Falcon
	Hill AFB	Ogden, UT	F-16 Fighting Falcon F-35 Lightning II
Navy	NAS Oceana	Virginia Beach, VA	F/A-18 Hornet
	NAS Lemoore	Lemoore, CA	F/A-18 Hornet
Marine Corps	MCAS Cherry Point	Havelock, NC	AV-8B Harrier EA-6B Prowler
	MCAS Yuma	Yuma, AZ	AV-8B Harrier F-35 Lightning II
	MCAS Miramar	San Diego, CA	F/A-18 Hornet

Source: GAO. | GAO-18-113

Note: AFB = Air Force Base; NAS = Naval Air Station; MCAS = Marine Corps Air Station

^a Due to the unavailability of fighter pilots at a location we had selected in the eastern portion of the contiguous United States, both of the Air Force locations we visited were located in the western portion of the contiguous United States.

To assess the extent to which the military services have reevaluated squadron requirements for the number of fighter pilots needed, including the consideration of UAS pilot requirements, we reviewed service guidance to determine the frequency with which elements of fighter pilot squadron requirements are to be reevaluated, reviewed service documentation, and interviewed service officials to determine the extent to which these elements had been reevaluated on schedule, reviewed service documentation regarding the planned mix of cockpit-operated and remotely-operated aviation platforms for future operations, and discussed with service officials the extent to which these plans are incorporated into forecasts of fighter pilot squadron requirements.

We conducted this performance audit from November 2016 to April 2018 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

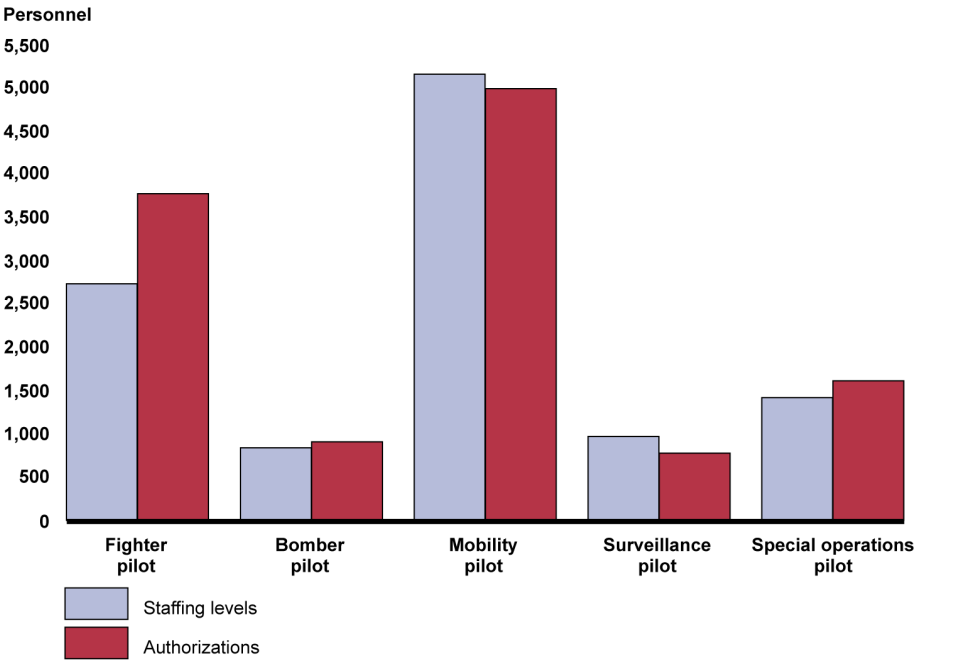
Appendix II: Comparison of Air Force Pilot Staffing Levels and Authorizations for Fixed-Wing, Cockpit-Operated Aircraft

The Air Force uses pilots from both the active and reserve components to staff fixed-wing, cockpit-operated (hereafter referred to as fixed-wing) aircraft pilot positions that Congress authorizes and funds through appropriations. These Air Force pilots staff a mix of operational and non-operational positions. Operational positions include both flying (e.g., combat pilot or instructor pilot positions) and non-flying positions (e.g., close air support duty officer positions in an Air Operations Center) that directly support combat operations. Non-operational positions are generally non-flying, and include assignments to headquarters or combatant command positions, some of which can be staffed by other types of Air Force officers. This appendix compares Air Force pilot staffing levels with authorizations for operational and non-operational positions for all fixed-wing aircraft communities for fiscal years 2006 through 2017.

Air Force fixed-wing community pilots operate fighter, bomber, mobility, surveillance, and special operations aircraft. Fighter pilots operate tactical aircraft that engage in air-to-air and air-to-surface attacks and include the A-10, F-15, F-16, F-22A, and F-35 aircraft. Bomber pilots operate aircraft to deliver munitions and include the B-1, B-2, and B-52 aircraft. Mobility pilots operate aircraft used for aerial refueling and troop and cargo transport and include the C-17 and KC-135 aircraft. Surveillance pilots operate aircraft used for surveillance and reconnaissance to support ground troops and include the E-8 and U-2 aircraft. Special operations pilots operate aircraft that provide close-air support for ground troops, including the AC-130.

Air Force officials report that they can staff certain operational positions designated for fighter pilots with pilots from other pilot communities that have surpluses. For example, Air Force officials told us they can staff mobility or surveillance pilots (communities which both had a surplus of pilots in fiscal year 2017) to certain basic flying training instructor pilot positions that would otherwise be staffed by fighter pilots. Figure 8 shows the Air Force active component fixed-wing aircraft community pilot staffing levels and authorizations for fiscal year 2017.

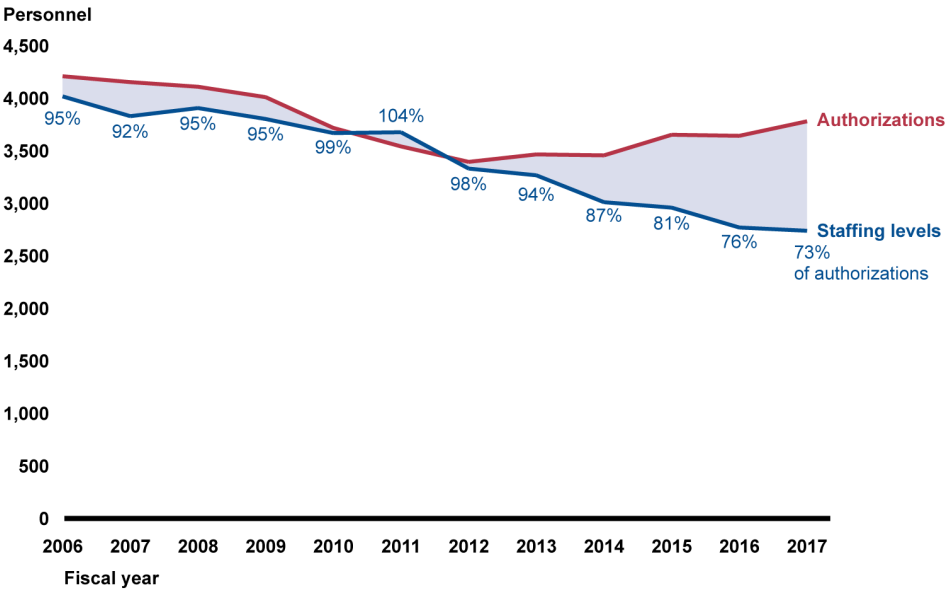
Figure 8: Comparison of Air Force’s Fixed-Wing Pilot Actual Staffing Levels with Authorizations, Fiscal Year 2017



Source: GAO analysis of Air Force data. | GAO-18-113

According to Air Force data for the active component, the Air Force had fewer fighter pilots than authorizations in 11 of 12 years from fiscal year 2006 through fiscal year 2017. This gap grew from 192 fighter pilots (5 percent of authorizations) in fiscal year 2006 to 1,005 (27 percent of authorizations) in fiscal year 2017. Figure 9 shows the comparison of the Air Force’s active component fighter pilot staffing levels with authorizations for fiscal years 2006 through 2017.

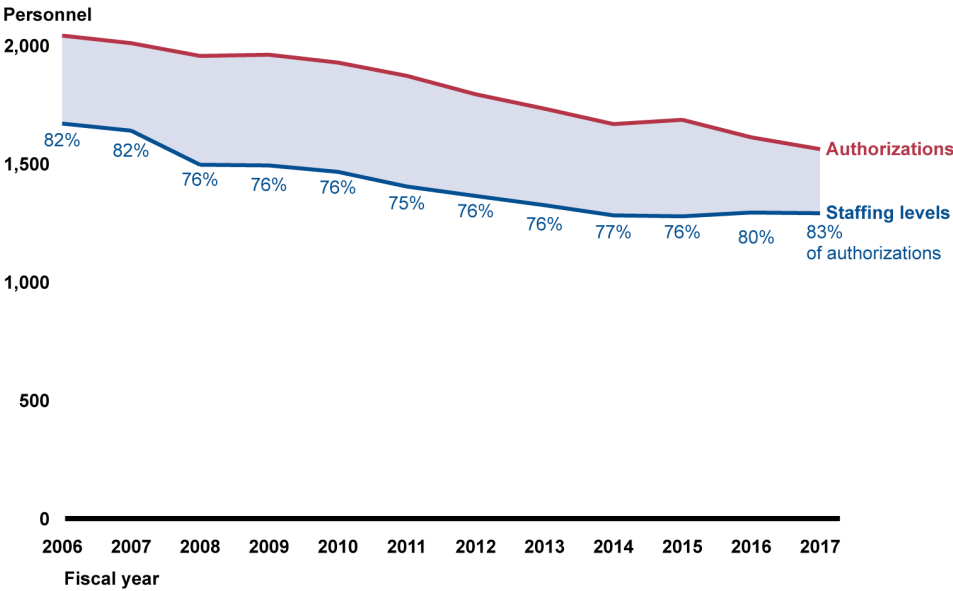
Figure 9: Air Force’s Active Component Fighter Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017



Source: GAO analysis of Air Force data. | GAO-18-113

According to Air Force data for the reserve components the Air National Guard and the Air Force Reserve, the Air Force had fewer fighter pilots than authorizations every fiscal year from fiscal year 2006 through 2017. For example, the Air Force reported that the reserve components had a gap of 271 fighter pilots (17 percent of authorizations) in fiscal year 2017. Figure 10 illustrates the gap between staffing levels and authorizations for Air Force fighter pilots in the reserve components for fiscal years 2006 through 2017.

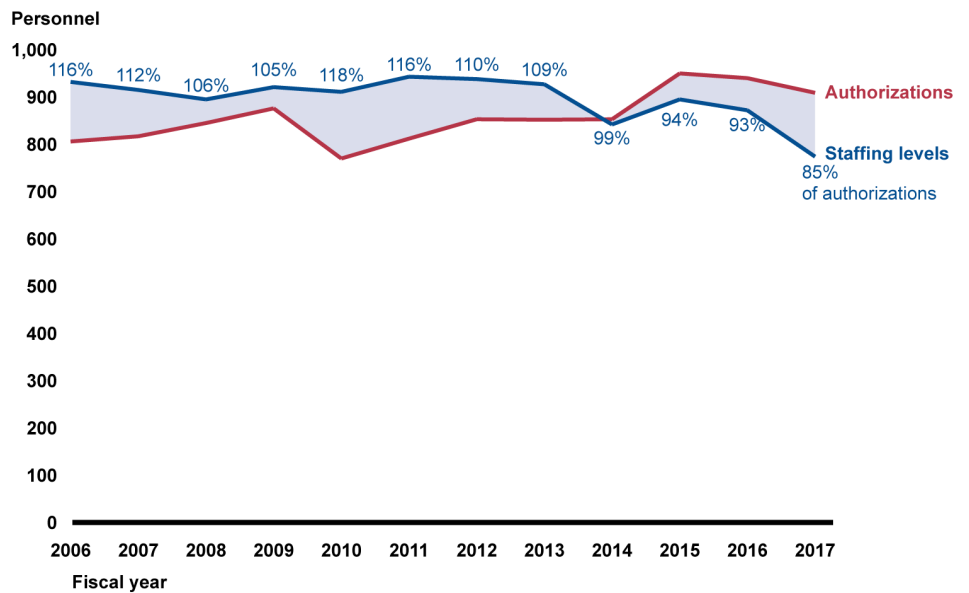
Figure 10: Air Force’s Reserve Component Fighter Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017



Source: GAO analysis of Air Force data. | GAO-18-113

According to Air Force data for the active component, the Air Force had fewer bomber pilots than authorizations in fiscal years 2014 through 2017. This gap grew from 11 bomber pilots (1 percent of authorizations) in fiscal year 2014 to 135 (15 percent of authorizations) in fiscal year 2017. Figure 11 shows the comparison of the Air Force’s active component bomber pilot staffing levels with authorizations for fiscal years 2006 through 2017.

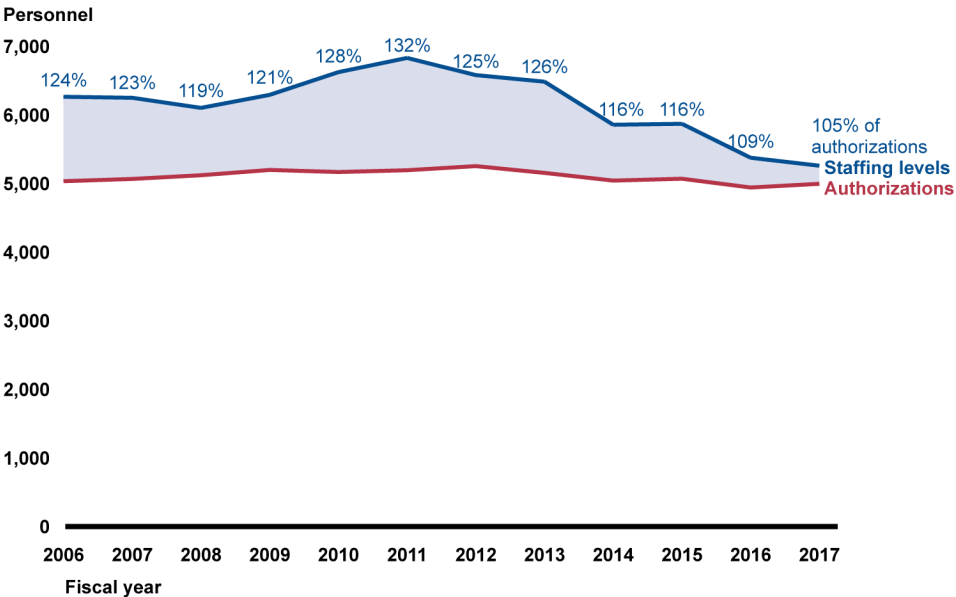
Figure 11: Air Force's Active Component Bomber Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017



Source: GAO analysis of Air Force data. | GAO-18-113

According to Air Force data for the active component, the Air Force had more mobility pilots than authorizations from fiscal year 2006 through fiscal year 2017. This surplus peaked at 1,637 mobility pilots (132 percent of authorizations) in fiscal year 2011, and declined to 264 (105 percent of authorizations) in fiscal year 2017. Figure 12 shows the comparison of the Air Force's active component mobility pilot staffing levels with authorizations for fiscal years 2006 through 2017.

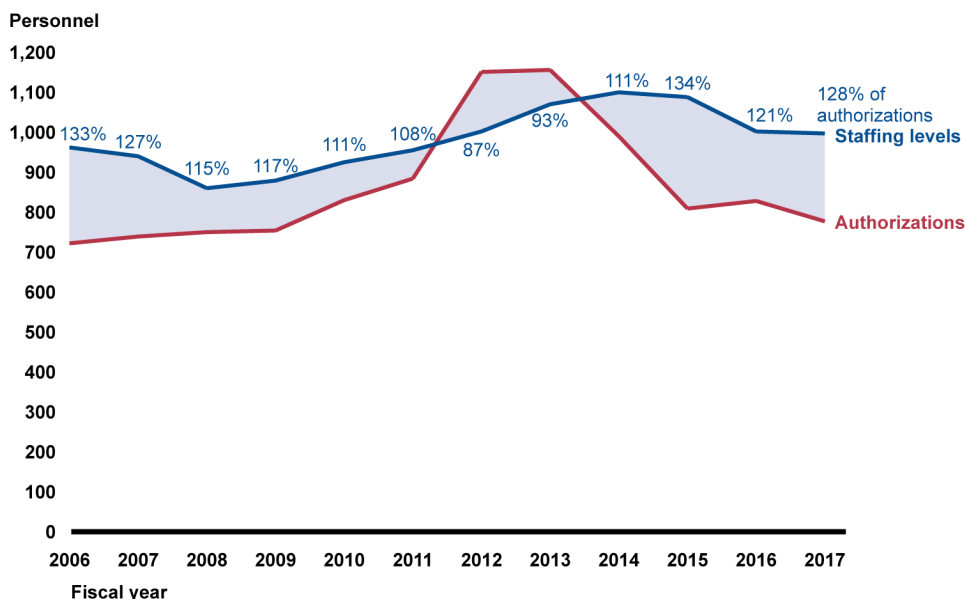
Figure 12: Air Force’s Active Component Mobility Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017



Source: GAO analysis of Air Force data. | GAO-18-113

According to Air Force data for the active component for fiscal years 2006 through 2017, the Air Force had fewer surveillance pilots than authorizations in fiscal years 2012 and 2013. In fiscal year 2017, the surplus was 220 surveillance pilots (128 percent of authorizations). Figure 13 shows the comparison of the Air Force’s active component surveillance pilot staffing levels with authorizations for fiscal years 2006 through 2017.

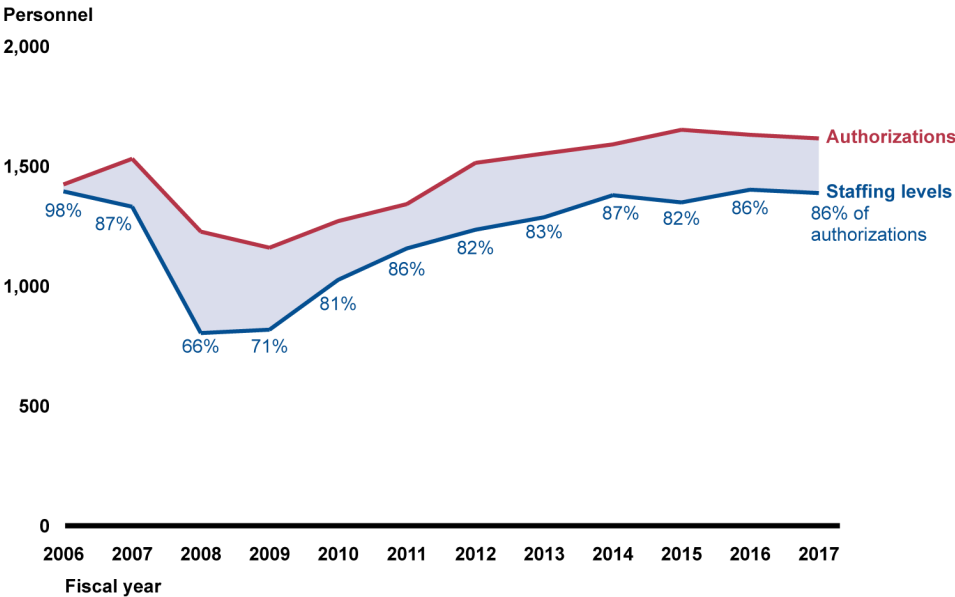
Figure 13: Air Force's Active Component Surveillance Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017



Source: GAO analysis of Air Force data. | GAO-18-113

According to Air Force data for the active component, the Air Force had fewer special operations pilots than authorizations from fiscal year 2006 through fiscal year 2017. Special operations pilot staffing levels and authorizations have increased substantially from fiscal year 2009 through fiscal year 2017. Further, the gap between the staffing levels and authorizations decreased from 342 special operations pilots (29 percent of authorizations) in fiscal year 2009 to 227 (14 percent of authorizations) in fiscal year 2017. Figure 14 shows the comparison of the Air Force's active component special operations pilot staffing levels with authorizations for fiscal years 2006 through 2017.

Figure 14: Air Force’s Active Component Special Operations Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017



Source: GAO analysis of Air Force data. | GAO-18-113

Appendix III: Comparison of Navy Pilot Staffing Levels and Authorizations for Fixed-Wing, Cockpit-Operated Aircraft

The Navy uses pilots from both the active and reserve component to staff fixed-wing, cockpit operated (hereafter referred to as fixed-wing) aircraft pilot positions that Congress authorizes and funds through appropriations. These Navy pilots staff a mix of operational and non-operational positions. Operational positions include both flying (i.e., combat pilot or instructor pilot) and non-flying positions that directly support combat operations. Non-operational positions are generally non-flying positions, and include assignments to positions at headquarters or in the combatant commands that can be staffed by other types of Navy officers.

The Navy does not separate non-operational fighter pilot authorizations from authorizations for other pilots. As a result, this appendix only presents Navy pilot staffing levels for those communities for fiscal years 2011 through 2017, and compares Navy pilot staffing levels to specific operational positions. Specifically, we compared authorizations and pilot staffing levels for Navy first operational tour, Department Head, and Command positions for all fixed-wing, cockpit-operated aircraft communities in the active component for fiscal years 2013 through 2017.¹

Navy fixed-wing community pilots operate fighter, surveillance and transport, and maritime patrol aircraft. Navy fighter pilots operate tactical aircraft for air defense and support. Fighter aircraft include both legacy and Super Hornet variants of the F/A-18,² as well as newer tactical aircraft such as the EA-18G developed for electronic warfare and the F-35. Surveillance and transport pilots operate turboprop aircraft, including the E-2D for surveillance and airborne early warning missions and the C-2A for troop and cargo transport between aircraft carriers and shore bases. Maritime patrol pilots operate jet aircraft for missions including anti-submarine warfare and anti-surface warfare, and include aircraft such as the P-8A.

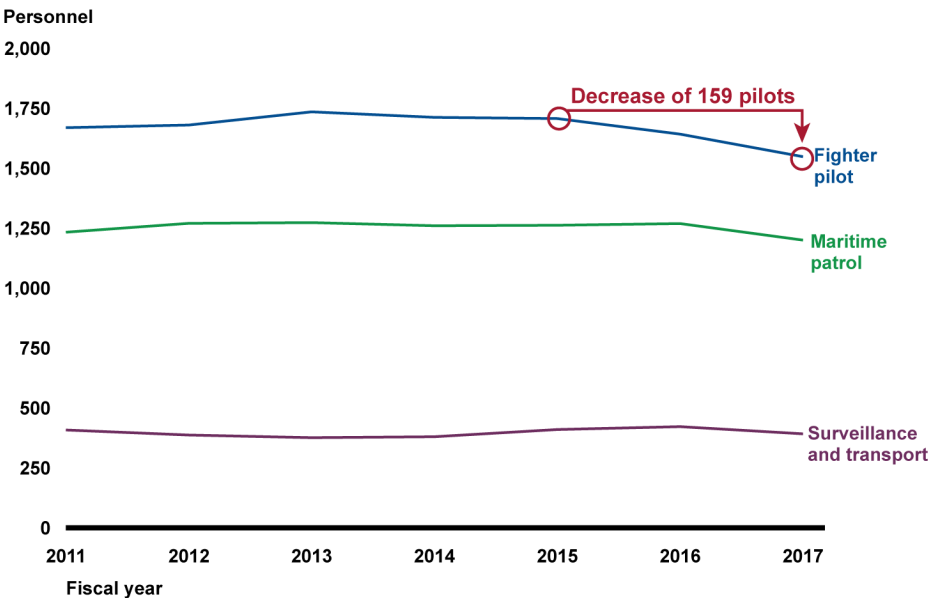
According to Navy personnel data, Navy fighter pilot staffing levels decreased from 1,707 fighter pilots in fiscal year 2015 to 1,548 (a 9-percent decrease) in fiscal year 2017. Figure 15 compares changes in the

¹ Staffing level data for the Navy Department Head and Command milestones include all Naval aviators –pilots and Naval Flight Officers (i.e. the officers that are responsible for navigation or weapon systems on cockpit-operated aircraft).

² All F/A-18 pilots conduct a range of missions, including air defense, fighter escort, and air support. Super Hornet pilots are additionally responsible for aerial refueling missions, air superiority, close air support, and precision strikes.

Navy fighter, surveillance and transport, and maritime patrol pilot staffing levels for fiscal years 2011 through 2017.

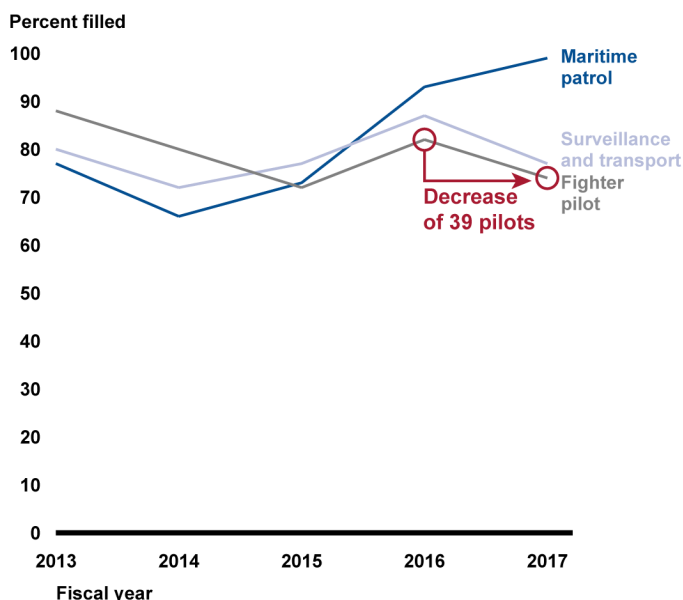
Figure 15: Navy’s Active Component Fixed-Wing Pilot Actual Staffing Levels, by Community, Fiscal Years 2011-2017



Source: GAO analysis of Navy data. | GAO-18-113

According to Navy fixed-wing pilot staffing levels and authorizations data for the first tour milestone (i.e., pilots’ first operational tours at sea for pilots generally with between 3 and 6 years of service), the Navy was unable to fully staff fighter pilot, surveillance and transport, and maritime patrol operational positions from fiscal years 2013 through 2017. The fighter pilot gap grew from 57 fighter pilots (12 percent of authorizations) in fiscal year 2013 to 136 fighter pilots (26 percent) in fiscal year 2017. The surveillance and transport pilot gap varied from 29 pilots (20 percent of authorizations) in fiscal year 2013 to 30 pilots (23 percent) in fiscal year 2017, while the maritime patrol community pilot gap decreased from 112 pilots (23 percent of authorizations) in fiscal year 2013 to 4 pilots (1 percent) in fiscal year 2017. Figure 16 compares the Navy active component fighter pilot, surveillance and transport, and maritime patrol communities’ first tour staffing levels and authorizations for operational positions for fiscal years 2013 through 2017.

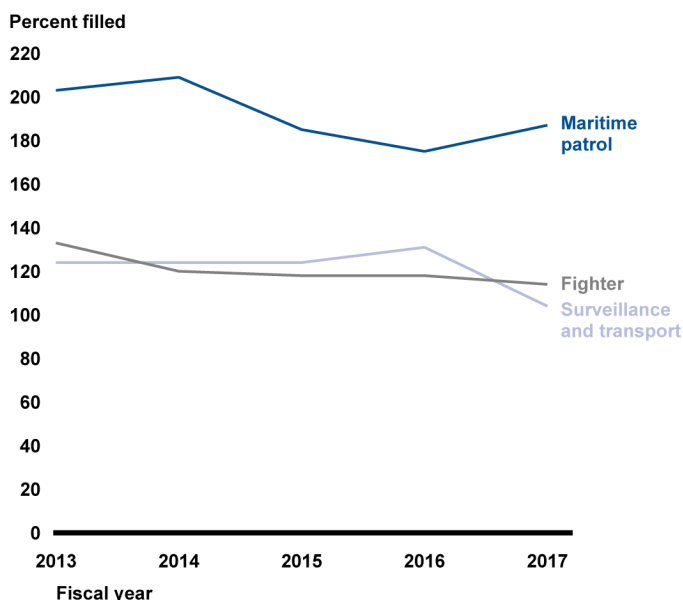
Figure 16: Navy's Active Component Fixed-Wing Pilot First Tour Pilot Actual Staffing Levels Compared with Authorizations for Operational Positions, Fiscal Years 2013-2017



Source: GAO analysis of Navy data. | GAO-18-113

According to Navy fixed-wing aviator staffing levels and authorizations data for the Department Head milestone (i.e., a mid-career operational leadership tour for different aspects of squadron management for pilots with between about 11 and 13 years of service), the military service had more fighter, surveillance and transport, and maritime patrol aviators than authorizations for fiscal years 2013 through 2017. However, the surplus of fighter aviators compared with authorizations decreased from 68 aviators (133 percent of authorizations) in fiscal year 2013 to 28 aviators (114 percent) in fiscal year 2017. Figure 17 compares the Navy active component fighter, surveillance and transport, and maritime patrol aviator communities' Department Head staffing levels and authorizations for operational positions for fiscal years 2013 through 2017.

Figure 17: Navy's Active Component Fixed-Wing Department Head Milestone Aviator Actual Staffing Levels Compared with Authorizations for Operational Positions, Fiscal Years 2013-2017

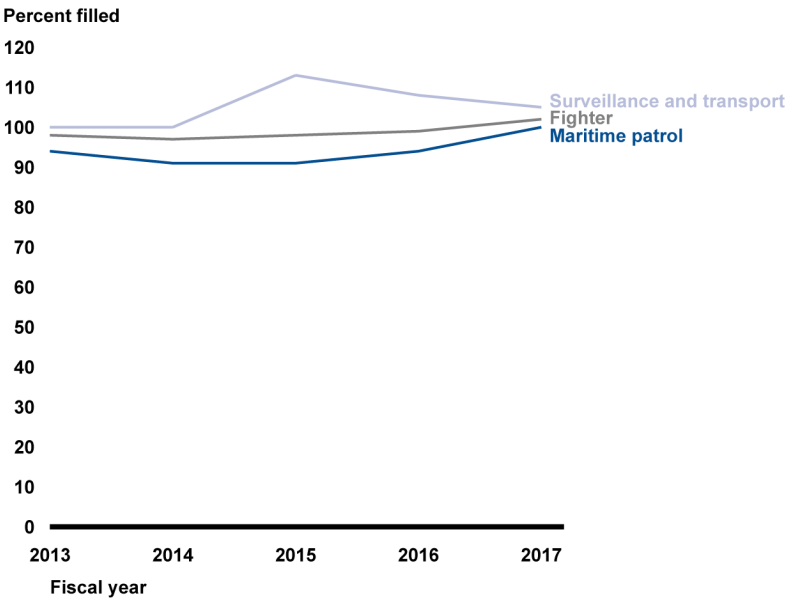


Source: GAO analysis of Navy data. | GAO-18-113

Note: These data include both pilots and Naval Flight Officers (non-pilot aviators responsible for navigation or weapon systems) because the Navy uses both types of personnel to staff Department Head positions. Navy officials told us that fluctuations in staffing levels at the Department Head milestone can be partially attributed to the timing of when these personnel move between assignments.

According to Navy fixed-wing aviator staffing levels and authorizations data for the Command milestone (i.e., a leadership tour for Commanders, including squadron commander, for aviators with between about 17 and 19 years of service) the number of fighter, surveillance and transport, and maritime patrol aviators compared with authorizations increased from fiscal years 2013 through 2017. For example, while the fighter pilot community had fewer aviators than authorizations in fiscal year 2013 (a gap totaling 2 percent of authorizations), it had a surplus of aviators in fiscal year 2017 (2 percent above authorizations). Figure 18 compares the Navy active component fighter, surveillance and transport, and maritime patrol aviator communities' Command milestone staffing levels and authorizations for fiscal years 2013 through 2017.

**Figure 18: Navy’s Active Component Fixed-Wing Command Milestone Aviator
Actual Staffing Levels Compared with Authorizations for Operational Positions,
Fiscal Years 2013-2017**



Source: GAO analysis of Navy data. | GAO-18-113

Note: These data include both pilots and Naval Flight Officers (non-pilot aviators responsible for navigation or weapon systems) because the Navy uses both types of personnel to staff Command positions. Navy officials told us that fluctuations in staffing levels at the Command milestone can be partially attributed to the timing of when these personnel move between assignments.

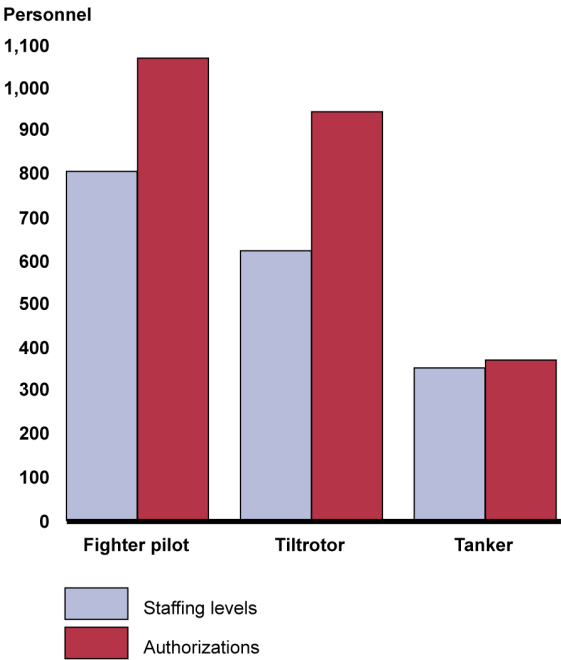
Appendix IV: Comparison of Marine Corps Pilot Staffing Levels and Authorizations for Fixed-Wing, Cockpit Operated Aircraft

The Marine Corps uses pilots from both the active and reserve components to staff fixed-wing, cockpit-operated (hereafter referred to as fixed-wing) aircraft pilot positions that Congress authorizes and funds through appropriations. These Marine Corps pilots staff a mix of operational and non-operational positions. Operational positions include both flying (e.g., combat pilot or instructor pilot positions) and non-flying positions (e.g., air controller in a ground infantry unit) that generally support combat operations. Non-operational positions are generally non-flying and include assignments to headquarters or combatant command positions, some of which can be staffed by other types of Marine Corps officers. This appendix compares Marine Corps pilot staffing levels with authorizations for operational and non-operational positions for all fixed-wing aircraft communities for fiscal years 2006 through 2017.

Marine Corps fixed-wing community pilots operate fighter, tiltrotor, and tanker aircraft. Fighter pilots operate tactical aircraft for air defense and close air support and attack missions, and include the EA-6B, AV-8B, F/A-18, and F-35. Tiltrotor pilots operate the MV-22—an aircraft that operates as a helicopter for takeoffs and landings and, once airborne, converts to a turboprop aircraft—and is used to transport combat troops and equipment. Tanker pilots operate the KC-130, an aircraft used for in-flight refueling and transport of troops and equipment.

According to Marine Corps data for the active component, the Marine Corps had fewer pilots than authorizations in all of its fixed-wing communities in fiscal year 2017. The Marine Corps forecasts this gap will persist through at least fiscal year 2023. Figure 19 shows the Marine Corps active component fixed-wing pilot staffing levels and authorizations for fiscal year 2017.

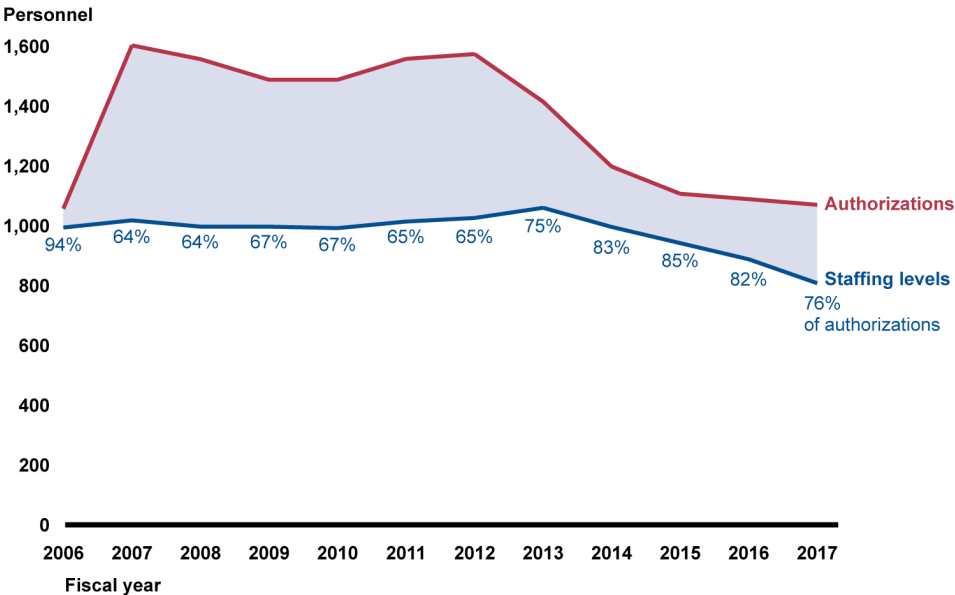
Figure 19: Marine Corps Fixed-Wing Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Year 2017



Source: GAO analysis of Marine Corps data. | GAO-18-113

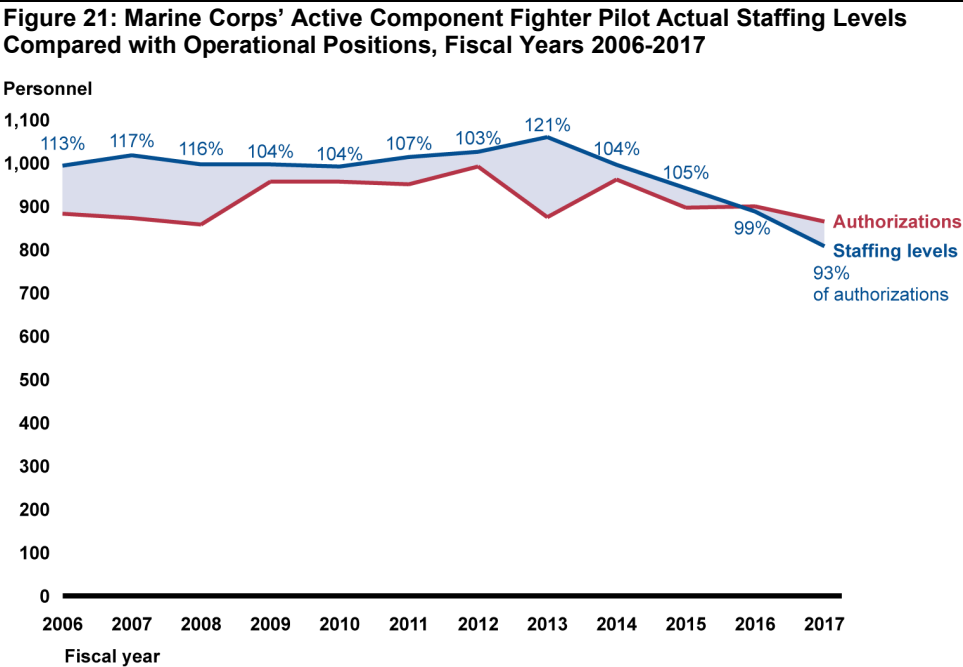
According to Marine Corps data for the active component, the Marine Corps had fewer fighter pilots than authorizations from fiscal year 2006 through fiscal year 2017. This gap grew from 63 fighter pilots (6 percent of authorizations) in fiscal year 2006 to 322 fighter pilots (24 percent) in fiscal year 2017. Figure 20 shows the comparison of the Marine Corps' active component fighter pilot staffing levels and authorizations for fiscal years 2006 through 2017.

Figure 20: Marine Corps' Active Component Fighter Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017



Source: GAO analysis of Marine Corps data. | GAO-18-113

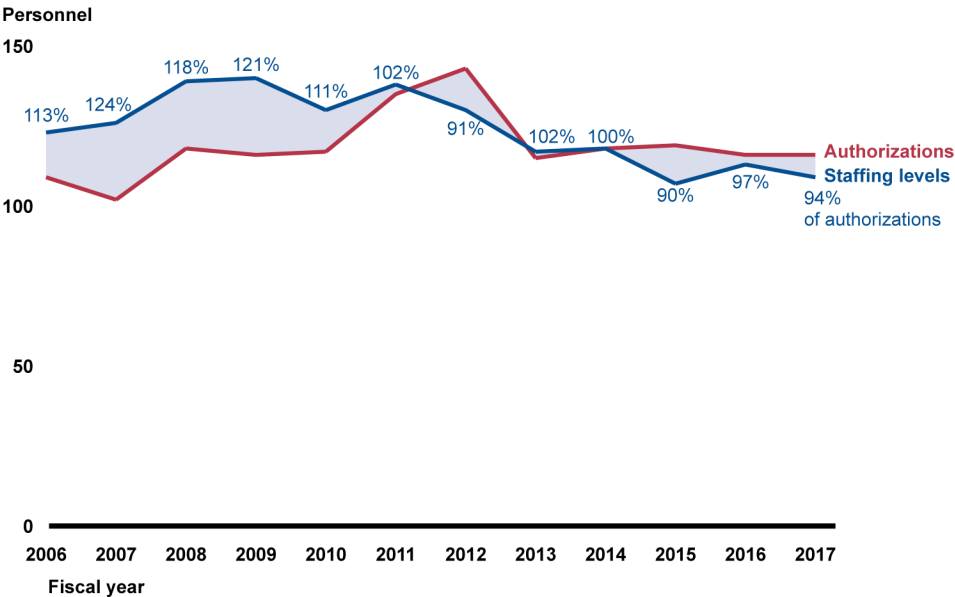
According to Marine Corps data for the active component, the Marine Corps had fewer fighter pilots than operational positions in fiscal years 2016 and 2017. Figure 21 shows the comparison of the Marine Corps' active component fighter pilot staffing levels with operational positions for fiscal years 2006 through 2017.



Source: GAO analysis of Marine Corps data. | GAO-18-113

According to Marine Corps data for the reserve component, the Marine Corps Reserve, a community that the Marine Corps uses to augment its available staffing levels of active duty pilots, had more fighter pilots than authorizations for 8 of 12 years in fiscal years 2006 through 2017. The Marine Corps had a gap of seven reserve component fighter pilots (6 percent of authorizations) for fiscal year 2017. Figure 22 shows the Marine Corps Reserve fighter pilot staffing levels and authorizations for fiscal years 2006 through 2017.

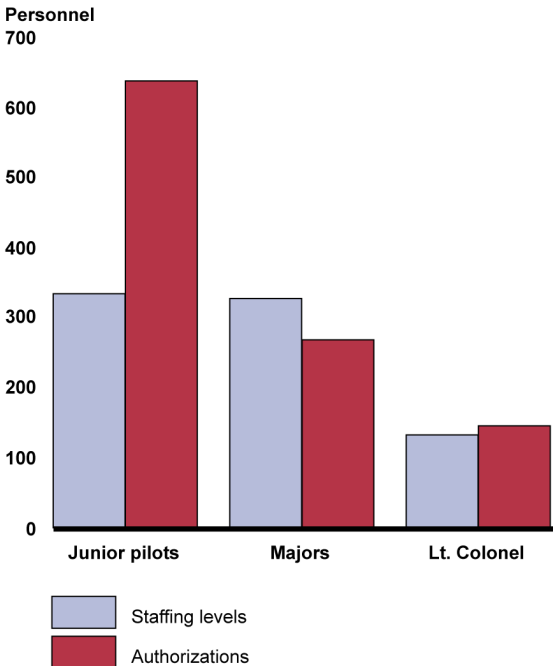
Figure 22: Marine Corps' Reserve Component Fighter Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017



Source: GAO analysis of Marine Corps data. | GAO-18-113

According to Marine Corps data for the active component, the Marine Corps had fewer junior fighter pilots—those pilots between grades Officer-1 and Officer-3—than authorizations from fiscal year 2006 through fiscal year 2017. Marine Corps officials told us that, as a result, the Marine Corps assigns pilots at the Officer-4 grade to staff positions designated for junior pilots. For example, in fiscal year 2017 the Marine Corps needed an additional 309 junior fighter pilots (48 percent of authorizations) to fill all authorizations. Figure 23 shows the comparison of the Marine Corps active component junior and senior fighter pilot staffing levels and authorizations for fiscal year 2017.

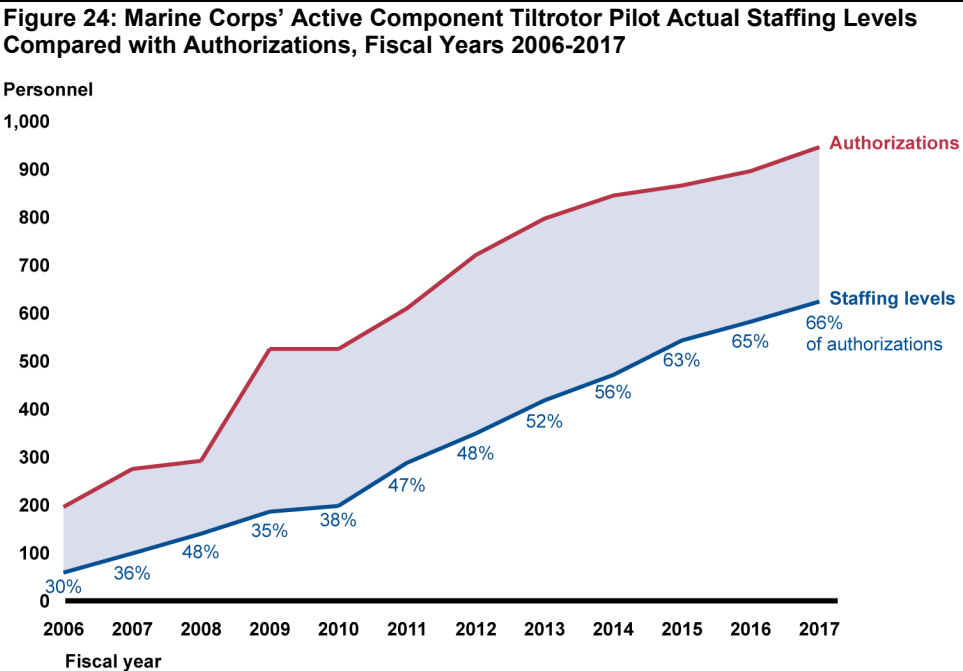
Figure 23: Marine Corps' Active Component Junior and Senior Fighter Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Year 2017



Source: GAO analysis of Marine Corps data. | GAO-18-113

Note: A junior pilot is an officer at the rank of Officer-1 through Officer-3. Majors are officers at the rank of Officer-4, and Lieutenant Colonels are officers at the rank of Officer-5. Both Majors and Lieutenant Colonels are considered to be senior officers.

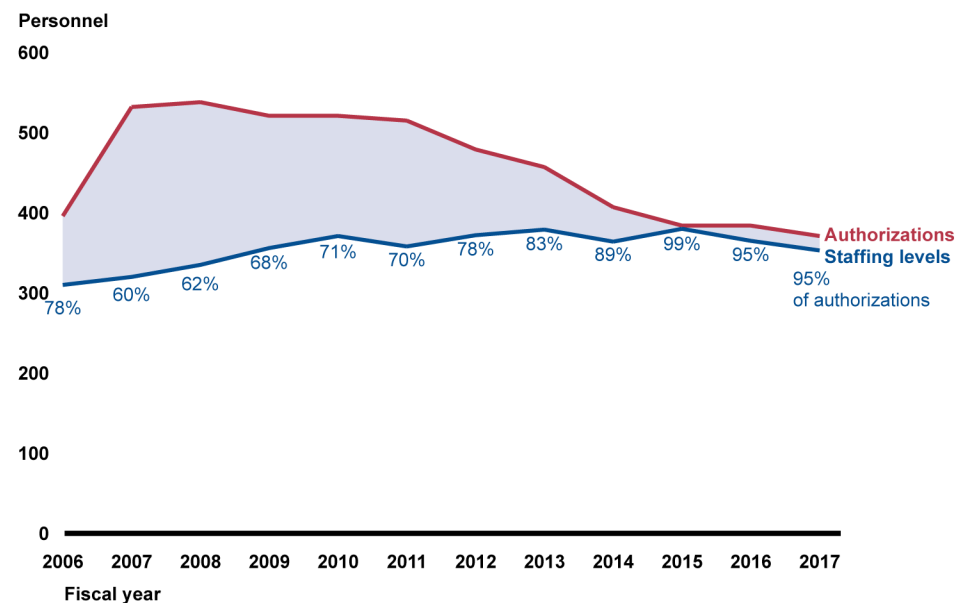
According to Marine Corps data for the active component, the Marine Corps had fewer tiltrotor pilots than authorizations from fiscal year 2006 through fiscal year 2017. Tiltrotor pilot staffing levels and authorizations have increased substantially from fiscal year 2006 through fiscal year 2017. Further, the gap between the staffing levels and authorizations has decreased from 137 tiltrotor pilots (70 percent of authorizations) in fiscal year 2006 to 322 tiltrotor pilots (34 percent of authorizations) in fiscal year 2017. Figure 24 shows the comparison of the Marine Corps active component tiltrotor pilot staffing levels and authorizations in fiscal years 2006 through 2017.



Source: GAO analysis of Marine Corps data. | GAO-18-113

According to Marine Corps active component data, the Marine Corps had fewer tanker pilots than authorizations from fiscal year 2006 through fiscal year 2017. This gap decreased from 86 tanker pilots in fiscal year 2006 (22 percent of authorizations) to 18 tanker pilots (5 percent of authorizations) in fiscal year 2017. Figure 25 shows the comparison of the Marine Corps active component tanker pilot staffing levels and authorizations for fiscal years 2006 through 2017.

Figure 25: Marine Corps' Active Component Tanker Pilot Actual Staffing Levels Compared with Authorizations, Fiscal Years 2006-2017



Source: GAO analysis of Marine Corps data. | GAO-18-113

Appendix V: Initiatives Implemented by the Air Force to Address Reported Fighter Pilot Shortages

In March 2016, the Chief of Staff of the Air Force created the Fighter Enterprise Tiger Team to address the fighter pilot shortage that the Air Force identified. In February 2017, the Air Force effort was expanded to include all rated personnel and renamed the Aircrew Crisis Task Force.¹ According to Air Force officials, the task force has focused on the following areas to improve fighter pilot retention: work/life balance, quality of service, and monetary compensation. In August 2017 the Aircrew Crisis Task Force held a Dedicated Aircrew Retention Team Summit that included organizing discussion groups with pilots to obtain information on retention challenges. According to Air Force officials, in September 2017, the task force presented 25 of the 44 recommendations developed at the summit to the Chief of Staff of the Air Force and as of November 2017 the Chief of Staff had decided to implement 2 of them immediately and conduct additional analysis on the other 23. The recommendations being analyzed include reducing the length and number of deployments for fighter pilots and converting some non-flying fighter pilot positions to UAS pilot positions. As of November 2017, these efforts had resulted in 37 implemented initiatives (see table 2).

Table 2: Air Force Fighter Enterprise Tiger Team and Aircrew Crisis Task Force Initiatives Implemented as of November 2017

Initiative	Target community	Implementation date
Encourage fighter wings to send fighter pilots and aircraft to undergraduate pilot training locations to advertise the fighter pilot career.	Fighter pilots	Summer 2016
Provide mentoring training to commanders of fighter wings and squadrons during major command (MAJCOM) squadron commanders' courses.	Fighter pilots	Summer 2016
Reviewed additional duties and reduced 29 additional administrative duties and 31 computer-based training courses.	All Air Force personnel	August 2016
Established Total Force Aircrew Management–Assignment Augmentation Program to allow 30 Air Force Guard or Reserve component pilots to fill vacant active duty assignments (both flying and non-flying) on 1-3 year orders.	Fighter pilots	Fall 2016
Inform junior fighter pilots of multiple career paths that lead to leadership opportunities through home station mentoring and deliberate training at squadron officer school.	Fighter pilots	Fall 2016
Educate fighter squadron leaders on the assignment process during MAJCOM squadron commanders' course.	Fighter pilots	Fall 2016
Place additional administrative staff in fighter squadrons. Currently implemented for Air Combat Command, in progress for U.S. Air Forces Europe, Pacific Air Forces, and Air Education and Training Command.	Fighter pilots	Fall 2016

¹ Rated personnel are servicemembers with an aeronautical rating including pilots, combat systems officers, and air battle managers.

Appendix V: Initiatives Implemented by the Air Force to Address Reported Fighter Pilot Shortages

Initiative	Target community	Implementation date
Review and validate 365-day deployments. Has reduced 24 positions designated for 365-day deployments to 179 days, and limited fighter pilot 365-day deployments only to those for command or joint staff assignments.	All aircrew	Fall 2016
Secured \$1,500/month in assignment incentive pay from six host nations to offset the negative retention impacts of foreign military sales assignments.	Fighter Pilots and weapons system officers	Fall 2016
Voluntary limited period of active duty program offers Guard and Reserve component personnel, including fighter pilots, the ability to return to active duty for 3-year orders, at a location of their choice, with no obligation to deploy. In the fighter pilot community, these personnel will generally staff positions that would otherwise go unstaffed due to the fighter pilot shortage.	All rated personnel	Fall 2016
Reinstate headquarters Air Force fighter awards.	Fighter pilots	September 2016
Allow officers to decline professional military education without being forced to separate.	All officers	November 2016
Create social media accounts to inform total force pilots of Air Force efforts to increase fighter pilot retention.	Fighter pilots	December 2016
Incentivize non-command 365-day deployments by offering pilots 2 more years of time on station or their choice of follow-on assignment.	All rated personnel	Spring 2017
Open fighter pilot individual deployments to other rated communities to mitigate the retention impact on fighter pilots.	Fighter pilots	Spring 2017
Air Combat Command secured funding that will allow the Air Force reserve component to staff 53 rated deployments in Fiscal Year 2018.	All rated personnel	Spring 2017
Implement comprehensive messaging campaign to ensure pilots are aware of Air Force efforts to mitigate aircrew shortfalls.	All aircrew	Spring 2017
Advertise 179/365-day deployments to reserve component.	Fighter pilots	Spring 2017
Drop average time on station during first combat-coded assignment from 2 years 8 months to 2 years 4 months to maximize available sorties for experiencing new pilots.	Fighter pilots	May 2017
Establish two new F-16 formal training units to help increase production to 285 active duty/335 total force fighter pilots per year.	Fighter pilots	June 2017
Advocate for congressional increases to aviation retention bonuses and aviation pay. Increases to both programs were authorized by the fiscal year 2017 National Defense Authorization Act.	Fighter pilots	June 2017
Chief of Staff of the Air Force directed a change to the process by which officers were selected for professional military education opportunities. The prior process contributed to retention problems as officers who were notified of non-selection were more likely to leave the Air Force. The new process provides wing leadership with increased authority to select officers for these opportunities.	All officers	July 2017
Adjust aviation bonus program to create eligibility for senior fighter pilots whose initial aviation bonus contract has expired.	All pilots	August 2017
Senior Pilot Transition Program selects senior instructor pilots in the fighter community to transition into the F-35 community to address the F-35 instructor pilot shortage. Service commitment of selected pilots is extended by 3 years, and pilots do not have to deploy.	Fighter pilots	August 2017

Appendix V: Initiatives Implemented by the Air Force to Address Reported Fighter Pilot Shortages

Initiative	Target community	Implementation date
Developed Combat Air Forces Fellowship program that allows 14 pilots to complete a residential professional military education assignment concurrently with a staff assignment, reducing the total time for these assignments from 3 years to 2 years, allowing for faster career progression.	Fighter pilots	August 2017
Address absorption limitations by sending inexperienced fighter pilots to the Navy to fly E/A-18 Growlers at Naval Air Station Whidbey Island, assist the Navy with fighter pilot production pipeline issues, and enhance tactical joint collaboration between the Navy and the Air Force.	Fighter pilots	Fall 2017
Increase experience levels of junior fighter pilots by placing them in aggressor squadrons.	Fighter pilots	Fall 2017
Reduce fighter pilot assignments to non-flying positions such as Army Air Liaison Officer, Reserve Officer Training Corps, and international assignments to train allied pilots on U.S. fighter aircraft.	Fighter pilots	September 2017
Create virtual staff positions that allow rated personnel to staff non-flying positions remotely, avoid relocating their families, and continue to fly enough to maintain currency so as to avoid a costly transition course to regain their flight certification.	All rated	September 2017
Second Assignment in Place program allows wing commanders to offer senior fighter pilots and combat system officers up to 6 years of continuous time on station at training and test squadrons.	Fighter pilots and combat system officers	September 2017
Placed 28 additional active duty fighter pilots into Air National Guard squadrons to provide experience opportunities.	Fighter pilots	October 2017
Develop an F-35 exchange with the Marine Corps so Air Force inexperienced pilots can gain experience and help to offset limitations in the Marine Corps fighter pilot production pipeline.	Fighter pilots	October 2017
Adjust exercise plan to enable eight fighter wings to execute a 1:5 deploy to dwell ratio, increasing time at home station for fighter pilots by 25-50 percent.	Air Combat Command fighter pilots	October 2017
Offer through the Voluntary Retired Return to Active Duty program retired fighter pilots the opportunity to return to active duty for non-flying and flying assignments.	All rated personnel	October 2017
Update software used to manage fighter pilot assignments to make the process more transparent and flexible.	Fighter pilots	Test started in November 2017
Offered experienced fighter pilots a “follow-on” assignment (i.e., guaranteeing the pilots’ choice of next assignment in return for volunteering for assignments that are difficult to staff).	Fighter pilots	November 2017
Preventative medical care for back and neck injuries.	Fighter pilots	Implemented at four locations (Portland Air National Guard Base, Kunsan Air Base, Royal Air Force Lakenheath, and Luke Air Force Base) as of November 2017, with funding for wider implementation scheduled through fiscal year 2020

Source: GAO analysis of Air Force information. | GAO-18-113

Appendix VI: Comments from the Department of Defense



MANPOWER AND
RESERVE AFFAIRS

OFFICE OF THE ASSISTANT SECRETARY OF DEFENSE
1500 DEFENSE PENTAGON
WASHINGTON, DC 20301-1500

MAR 22 2018

Ms. Brenda Farrell
Director, Defense Capabilities Management
U.S. Government Accountability Office
441 G Street, NW
Washington, DC 20548

Dear Ms. Farrell,

This is the Department of Defense (DoD) response to the GAO Draft Report, GAO-18-113, 'MILITARY PERSONNEL: DoD Needs to Reevaluate Fighter Pilot Workforce Requirements,' dated February 8, 2018 (GAO Code 101254).

The Department has a number of initiatives and efforts underway to address the ongoing shortage of military aviators. As the Department seeks to improve and sustain readiness, maximize the lethality of the force, and increase capability and capacity, we are committed to ensuring the size, structure, composition, and mix of our workforce supports the diverse and varied mission sets of the aviation community, including those associated with fighter pilots; remotely piloted aircraft operations; air mobility capabilities; rotary wing operations; and aviation maintenance, command & control, and support functions. Accordingly, the Department is committed to addressing manpower, personnel, and training challenges for our fighter pilot community and our broader aviation and aviation support capabilities. Better outcomes can be achieved, in part, through reevaluation of fighter pilot squadron requirements, updating workload assumptions, ensuring an optimized manpower structure and mix, and improving training pipelines to produce the capabilities and capacity necessary to achieve our missions.

The Department's responses to the specific recommendations are in the enclosure. Should you have any questions, please contact my primary action officer for this engagement, Mr. Thomas Hessel at 703-697-3402 or thomas.j.hessel.civ@mail.mil.

Sincerely,

A handwritten signature in black ink, appearing to read "Rich Robbins", is written over a horizontal line.

Rich Robbins
Director, Total Force Manpower &
Resources

Enclosure

**GAO Draft Report Dated February 8, 2018
GAO-18-113 (GAO CODE 101254)**

**“MILITARY PERSONNEL: DOD NEEDS TO REEVALUATE FIGHTER PILOT
WORKFORCE REQUIREMENTS”**

**DEPARTMENT OF DEFENSE COMMENTS
TO THE GAO RECOMMENDATION**

RECOMMENDATION 1: The GAO recommends that the Secretary of the Air Force ensure that the Director of Operations (AF/A3O) and the Air Force Manpower Analysis Agency reevaluate fighter pilot squadron requirements, to include updating current assumptions of fighter pilot workload, and assessing the impact of future incorporation of UAS platforms into combat aviation.

DoD RESPONSE: Concur. The Department notes that across the Air Force, many organizations and offices, in addition to the Director of Operations and Air Force Manpower Analysis Agency will play integral roles in determining the future size and mix of manpower requirements for fighter pilot squadrons.

Over the past decade, the Air Force has decreased overall manpower authorizations while simultaneously growing space, cyber, and persistent intelligence, surveillance, and reconnaissance (ISR) authorizations. As a result, fighter squadron crew ratios dropped from 1.5 pilots per aircraft to 1.25. At the same time, thousands of support authorizations were eliminated, while changes to aircraft tactics and technology increased training requirements. The result of these actions was an increase in workload for the fighter pilots. Consequently, the Air Force began mitigating the lack of fighter squadron administrative support in 2016 by funding contracted support in each fighter squadron to accomplish non-operational tasks. That effort continued in 2017 with the Air Force funding an additional 1,600 Commander Support Staff (CSS) authorizations for all squadrons. The Air Force will also review fighter wing manpower determinants to accurately account for fighter pilot workloads and analyze support organization manning to ensure adequate support to operational units.

The burgeoning Remotely Piloted Aircraft (RPA) community has already replaced some fighter pilots on staffs with RPA pilots. The Air Force is committed to ensuring efficient use of limited manpower resources and will closely monitor ways to leverage manpower in the growing RPA community to mitigate fighter pilot staffing shortfalls. Finally, the unique “deployed in place” operations of many RPA aircrews demands the Air Force apply the same scrutiny to associated operational and support manpower determinants to ensure lessons learned while addressing fighter pilot workloads are also applied in this community.

RECOMMENDATION 2: The GAO recommends that the Secretary of the Navy ensure that the Chief of Naval Operations reevaluate fighter pilot squadron requirements, to include updating current assumptions of fighter pilot workload, and assessing the impact of future incorporation of UAS platforms into combat aviation.

DoD RESPONSE: Concur. The Department notes that the across the Navy, many organizations and offices, including the resource sponsor, Naval Air Forces, will play integral roles in determining the future size and mix of manpower requirements for fighter pilot squadrons.

RECOMMENDATION 3: The Secretary of the Navy should ensure that the Commandant of the Marine Corps and the Deputy Commandant for Aviation reevaluate fighter pilot squadron requirements.

DoD RESPONSE: Concur. The Department notes that across the Marine Corps, many organizations and offices in addition to the Deputy Commandant for Aviation, play integral roles in the continuous evaluation and determination regarding current and future size and mix of manpower requirements for fighter and attack squadrons.

Appendix VII: GAO Contact and Staff Acknowledgments

GAO Contact

Brenda S. Farrell, (202) 512-3604 or farrellb@gao.gov

Staff Acknowledgments

In addition to the contact named above, key contributors to this report were Lori Atkinson, Assistant Director; Vincent Buquicchio, Timothy Carr, Mae Jones, Foster Kerrison, Amie Lesser, Michael Silver, and Nell Williams.

Related GAO Products

Military Personnel: Actions Needed to Better Position the Navy and the Marine Corps to Support Expanding Unmanned Systems Operations. [GAO-18-162](#). Washington, D.C.: February 6, 2018.

Department of Defense: Actions Needed to Address Five Key Mission Challenges. [GAO-17-369](#). Washington, D.C.: June 13, 2017.

DOD Training: DOD Has Taken Steps to Assess Common Military Training. [GAO-17-468](#). Washington, D.C.: May 23, 2017.

Navy Force Structure: Actions Needed to Ensure Proper Size and Composition of Ship Crews. [GAO-17-413](#). Washington, D.C.: May 18, 2017.

High Risk Series: Progress on Many High-Risk Areas, While Substantial Efforts Needed on Others. [GAO-17-317](#). Washington, D.C.: February 15, 2017.

Military Compensation: Additional Actions Are Needed to Better Manage Special and Incentive Pay Programs. [GAO-17-39](#). Washington, D.C.: February 3, 2017.

Unmanned Aerial Systems: Air Force and Army Should Improve Human Capital Planning for Pilot Workforces. [GAO-17-53](#). Washington, D.C.: January 31, 2017.

Unmanned Aerial Systems: Further Actions Needed to Fully Address Air Force and Army Pilot Workforce Challenges. [GAO-16-527T](#). Washington, D.C.: March 16, 2016.

Unmanned Aerial Systems: Actions Needed to Improve DOD Pilot Training. [GAO-15-461](#). Washington, D.C.: May 14, 2015.

Air Force: Actions Needed to Strengthen Management of Unmanned Aerial System Pilots. [GAO-14-316](#). Washington, D.C.: April 10, 2014.

Tactical Aircraft: DOD's Ability to Meet Future Requirements Is Uncertain, with Key Analyses Needed to Inform Upcoming Investment Decisions. [GAO-10-789](#). Washington, D.C.: July 29, 2010.

Unmanned Aircraft Systems: Comprehensive Planning and a Results-Oriented Training Strategy Are Needed to Support Growing Inventories. [GAO-10-331](#). Washington, D.C.: March 26, 2010.

Human Capital: Key Principles for Effective Strategic Workforce Planning. [GAO-04-39](#). Washington, D.C.: December 11, 2003.

Military Personnel: Actions Needed to Better Define Pilot Requirements and Promote Retention. [GAO/NSIAD-99-211](#). Washington, D.C.: August 20, 1999.

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Please Print on Recycled Paper.

Case Study of US Fighter Pilots Incurring Injuries Caused by Dynamic Maneuvering

And

(Being Denied a Disability Rating from the Veterans Administration)

April 13, 2018



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TABLE OF CONTENTS

Case Study of US Fighter Pilots Incurring Injuries Caused by Dynamic Maneuvering	1
TABLE OF CONTENTS	2
Prologue	3
For Addition Information.....	3
Duane Lodrige, Brigadier General, USAF (ret).....	3
Objective.....	4
Essential Elements of the Problem.....	6
Summary by Brigadier General Duane Lodrige, USAF (ret).....	8
The Study and Pilot Survey Responses – LtCol Jim McMichael, USAF (ret)	12
Average Tactical Jet Flight Hours by Survey Respondents	13
Survey response - Cervical or Lumbar injury claim & if surgery was required.....	14
Survey Response – Type of Jets Flown	14
What gets broken in the long-term.....	15
How many injured survey pilots were denied a disability rating from the VA.....	16
What can be done	17
Appendix I– Medical Studies – COL Roger Kemp, M.D.....	18
Appendix II – Additional Research.....	21
Appendix III – Surveyed Pilot Comments	27
Appendix IV – A Smoking Gun?	34
Appendix V – Addition Medical Research – Brigadier General Duane Lodrige, USAF (ret)	36
Appendix VI – Reserve Officers Association Approved Resolution	42
Appendix VII – Paratrooper Appeal Granted by VA 2009	43

Prologue

This report was crafted to aid our elected representatives with the necessary information needed to change policy at the Veterans Administration with respect to medical disability claims submitted by fighter pilots. These veterans who flew high performance aircraft endured double-digit years of physical exposure to high gravitation forces (Gz) during both training sorties and combat operations on a daily basis.

United States Fighter pilots are professionals who accept the duty and responsibility of protecting and defending this nation. The grueling high Gz environment has been documented by aeromedical professionals worldwide, as the reason, fighter pilots suffer long-term hazards and degeneration of their cervical and lumbar spines.

This report will include data and comments collected by active duty (AD), Reserve and Air National Guard pilots who have flown or are flying the F-16 Fighting Falcon, F/A-18 Hornet & Super Hornet, F-35A/B and the F-22. The reader will also see information provided from pilots of legacy jet fighters such as the F-4, RF-4C, and F-105.

The main issue being addressed in this report is the Veterans Administration's consistent denial of disability claims and service connection for injuries when the veteran's military medical records are unavailable or line-of-duty medical documentation is not on file.



For Additional Information, Contact
Duane Lodrige, Brigadier General, USAF (ret)
email: veteranfigtherpilots@gmail.com

Objective

The objective of this document is to show, textually, graphically, medically, and anecdotally, how repetitive strain injuries [RSI] are debilitating and permanently injurious to today's 4th and 5th generation fighter pilots, and that incapacitating injuries in later life are due to the ongoing RSI during their flight careers.

Fighter pilots are subjected to the repeated stresses of G maneuvering in the course of training or combat missions. Studies conclude that G loading of the spine causes both acutely debilitating and minor tears and damage (RSI) to soft tissue. Countless studies attached in appendix V conclude that fighter pilots, especially those flying 4th generation [F-16] and later high performance aircraft sustain both acute and severe degenerative spinal injuries.

RSI are a well-known, and well documented type of injury to people in all types of civilian work and acknowledged for health benefit claims.

Why? Because it is well documented that continual stresses of soft tissue protecting bone joints, left untreated and/or treated but not given sufficient time to heal, will eventually, and this can take years, lead to permanent damage especially to the spine.

Serious injuries to fighter pilots due to RSI are not consistently recognized for health benefits when they result in serious damage years after retirement. Yet, paratroopers who are subjected to similar RSI are recognized.

WE HAVE AMASSED OVER 925 PILOT CASES WITH A VARIETY OF SPINE INJURIES, as is listed in **APPENDIX III** of this document.

We are NOT presenting a “case controlled” study.

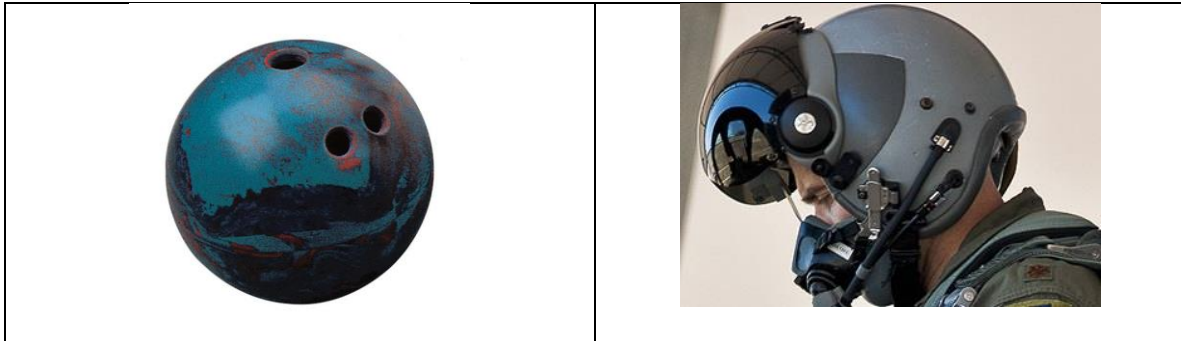
We have empirical data from “face-to-face” interviews with OVER 925 retired fighter pilots primarily from the F-16 community but the same issues exist with pilots from other high performance modern fighters including the F-15, F-18, F-22, and F-35.

Overall, there is a pervasive lack of understanding and recognition by the VA regarding both the acute (single event) and chronic (long term) spinal damage to the human body caused by years of “high G maneuvering” in modern fighter jet aircraft. Despite the over whelming evidence of numerous medical studies, the VA refuses to acknowledge this as an issue, as evidenced by a large number of claim denials and inconsistent claims ratings.



Essential Elements of the Problem

This paper shall begin by asking the reader to identify the similarity between these two pictures.



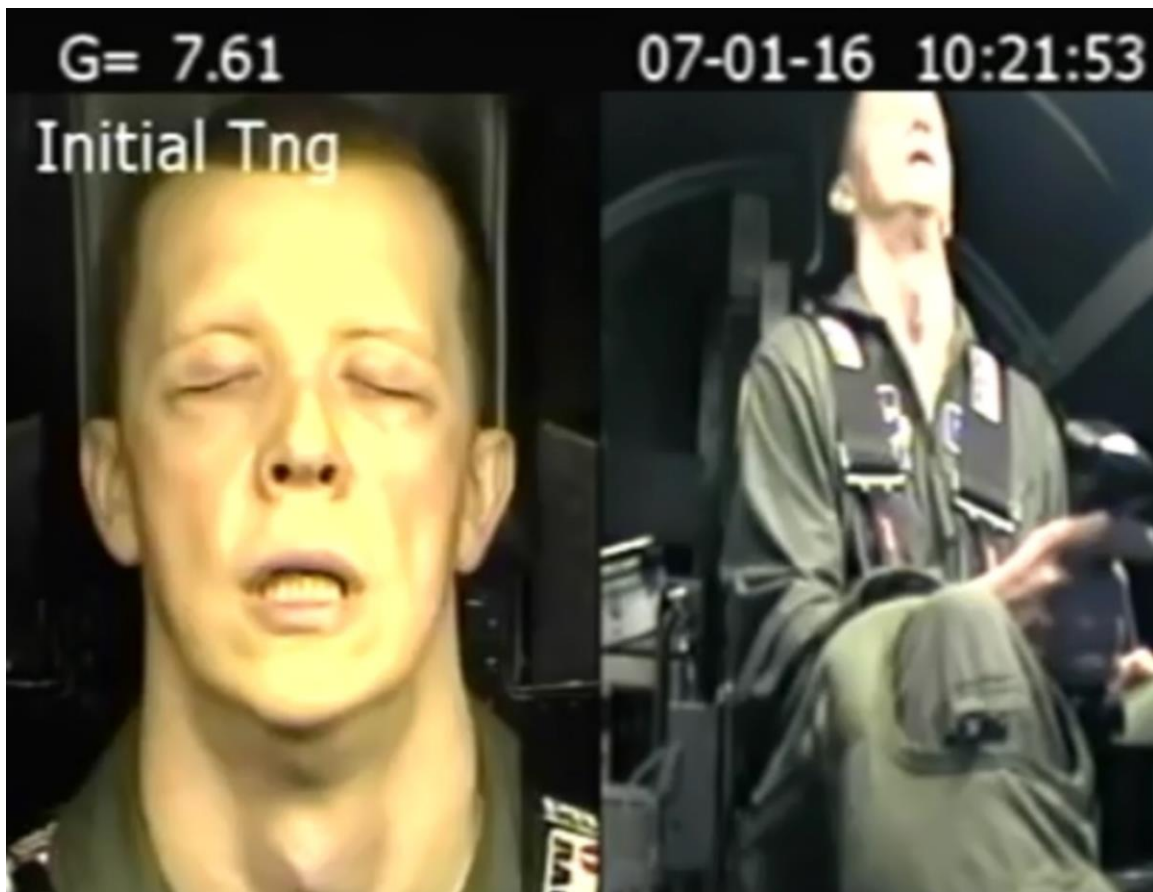
According to the Expert Bowler magazine, “The average adult male will use a ball that weighs between 14 and 16 pounds with females requiring a ball of between 10 to 14 pounds” (Expert Bowler, 2018). Medical professionals agree that the average weight of an adult human male’s head is 8.5 pounds. According to the United States Air Force, the weight of the standard flight helmet including the oxygen mask, built-in radio and enhanced vision visors is 4.3 pounds. **A fighter pilot encountering 9 times the force of gravity, known as 9 Gz, which typically is experienced during multiple training sorties per week or daily during combat operations, neck and spine carries the combined weight of six and a half (6.6) bowling balls on their neck.** Then add experiencing that for 20 years or more and ask yourself, would a reasonable person conclude the possibility of long-term damage to the pilot’s neck and lumbar spine is possible? Helmets may also include additional weight from Night Vision Goggles (NVGs) and the more modern Joint Helmet Mounted Cueing System (JHMCS). For the last decade many academic and medical studies have been conducted and support that conclusion. The United States Department of Veteran Affairs, however, requires more proof.

Supersonic tactical jet fighter pilots of the United States Air Force (USAF), United States Navy (USN) and the United States Marine Corps (USMC) are routinely exposed to high positive Gz forces and negative Gz during flight training or combat operations. The pilot’s neck and spine are stretched (during negative Gz flight) or severely compressed (during high positive Gz flight maneuvers) and even encounter twisting.

Fighter pilots complete flights of these types with injuries to their neck, lower spine or both. Even when the pain or damage is acute, they do not report to the flight surgeon due to concerns of being grounded temporarily or permanently.

The compressing and twisting or stretching and twisting have medically been proven to manifest long-term damage. Yet, when a fighter pilot has retired from the military, physical issues from the neuro-muscular-skeletal damage manifest, they apply for a disability rating from the Veterans Administration and may become inclusive to the nearly 40% that are automatically denied due to lack of service related line-of-duty medical documentation to support the claim.

The following picture is a pilot experiencing 7.6 Gz in a centrifuge.



Summary by Brigadier General Duane Lodrige, USAF (ret)

It is my belief and the belief of many veteran fighter aviators and the military aeromedical community that there is a pervasive lack of understanding and recognition by the VA regarding both the acute (single event) and chronic (long term) spinal damage to the human body caused by years of “high G maneuvering” in modern fighter jet aircraft. Despite the over whelming evidence of numerous medical studies, the VA refuses to acknowledge this as an issue, as evidenced by a large number of claim denials and inconsistent claims ratings.

Since the 1980's the aeromedical community worldwide has recognized that the intensity and duration of exposure to +Gz forces causes various spine related pathologies. In fact, NATO has produced multiple multi-national medical reports regarding “Neck Injury in Advanced Military Aircraft Environments”. Spinal injuries and pain are common for pilots in high performance fighter aircraft and are attributed to high gravitational forces, non-neutral head positions, and modern equipment such as heavy helmets and night vision goggles. The incidence of reported cervical/lumbar pains and injuries greatly increased with the introduction of newer, more capable fourth generation aircraft (F-15,F-16,F-18). The prevalence of spinal injuries is highest in the F-16 where pilots reported a 90% occurrence of an acute spine injury during their careers and 60% in the past 90 days.

The USAF issued guidance in the late 80's continuing into the 90's regarding physical fitness regimens to decrease back and neck injuries. Even today, the USAF is conducting multiple studies at the Human Factors Lab at Wright Patterson AFB, Ohio regards the physiological impact of fighter aircraft and associated cockpit equipment (helmets, night vision goggles, ejection seats, etc.) With the advent of Advanced +Gz breathing systems such as Combat Edge in the 1990's, pilots can routinely fly at higher +Gz without losing consciousness, thus more high G exposure is sustained over the lifetime of the pilot. More exposure to high +Gz have led to increased G-loading on the spine increasing the environmental health risk for fighter pilots.

In 1989, a NATO aeromedical symposium made three conclusions regarding exposure to maneuvering G:

1. Acute injuries commonly occur that involve soft and hard tissues of the neck,

2. Repetitive exposures probably lead to spinal degenerative changes in the cervical spine,
3. There is a need to include chronic injury in the classification scheme for neck injuries.

It is obvious from past multi-national studies that aviators worldwide are suffering from not only acute injuries but the cumulative nature of “repetitive stress injuries (RSI) not “old age “osteoarthritis, as the VA would like to maintain. As OFTEN, THE SEVERITY OF FIGHTER PILOT CERVICAL AND LUMBAR SPINE ISSUES DOES NOT MANIFEST ITSELF UNTIL LATER IN LIFE.

To proceed:

There are many articles and studies of the effect of whiplash on the neck muscles, ligaments, and soft tissue. And claims are successfully adjudicated for medical benefits. Even if the claims are made months after the injurious event(s) occurred.

As noted in several studies on fighter pilot cervical spine, another medical injury category which has been well studied and researched and documented is various forms of arthritis.

Since this ailment appears mostly in age groups greater than 45yrs, it has been **falsely** assumed that resultant injuries to retired fighter pilots in later life, is due to a normal aging process and “old age” arthritis.

Osteoarthritis is a chronic disorder associated with damage to the cartilage and surrounding tissues and characterized by pain, stiffness, and loss of function. Arthritis due to damage of joint cartilage and surrounding tissues becomes very common with aging. Osteoarthritis, the most common joint disorder, often begins in the 40s and 50s and affects almost all people to some degree by age 80. How does this damage manifest itself in fight pilots? And when and how does the damage occur in fighter pilots? It is well documented in multiple studies, along with details of soft tissue stresses over LONG periods of time. The overwhelming majority of fighter pilots are subjected to the cumulative toll of +G loading from the beginning of their training in the early twenties. There is a direct correlation between total high performance flying hours and spine degradation. The cumulative and repetitive toll of high +Gz eventually not only damages vertebrae, but severely compromise the integrity of the cushioning characteristics

of the soft tissue. For the vast majority of fighter pilots, it's only a matter of when he/she will feel the cumulative effects of +Gz.

As a reference some historical precedence of “after the fact” injuries due to repetitive stresses/strains are:

- Smoking, even secondary, resulting in lung damage, cancer.
- Football helmet-to-helmet or boxing hard contacts resulting in severe brain damage in later life
- Baseball pitchers suffering from repeated throwing actions which eventually caused torn elbow ligaments. This became known as TOMMY JOHN surgery.

All these and other RSI actions in private occupations after medical research and study were acknowledged as work injuries and proper cause for medical benefits. Yet in the military environment, where RSI for fighter pilots is a normal event, injured aircrew members are not receiving the recognition or treatment needed.

The position that these injuries are due to “old age” would appear ***incorrect at the very least!*** The fact that they were not reported during active duty relates to studies that indicate most of these pains and stresses may not be acutely debilitating at the time!

One issue consistently raised by the VA and used for claims denial is a lack of documentation in pilot's military medical records. Frequently, they work quietly behind the scenes to take a few days off the flight schedule by performing non-flying duties while their cold goes away, or their back problems subside. **Not only does the science show the link between +Gz and degenerative spinal damage but conversations with several former flight surgeons and fighter squadron commanders emphatically confirm the prevalence of spinal issues within the fighter pilot community and the universal desire to avoid being “grounded” by seeking medical treatment. Most** fighter pilots are young and “bullet proof” so they tend to ignore the common muscle strains, aches, and pains associated with the high “G” environment. Consequently, when they leave the service, they may have permanent but “silent” spinal damage. The VA does not link their condition with their military service as they don't have adequate documentation in their military medical record.

Conclusion:

Multiple studies by multiple countries and military branches have come to the same conclusion.

Body stresses due to maneuvers of high performance fighter, and other aircraft result in lasting damage to body soft tissue.

The facts should lead to appropriate recognition by the VA for fighter pilot claims related to spinal damage associated with flying high performance fighter aircraft over extended years of service.

PRECEDENT>Whereas RSI was only considered in terms of private occupations, no articles on RSI considered RSI in the military “occupations”. This ruling, along with all studies on RSI lasting damage **DID NOT CONSIDER MILITARY ACTIVITIES.**



The Study and Pilot Survey Responses – LtCol Jim McMichael, USAF (ret)

The basis for this document began in 2015 with a fighter pilot who was diagnosed with a severe spinal injury, post retirement, and applied unsuccessfully to the VA for a disability rating. He posted on social media via Facebook for advice from 4th and 5th gen fighter pilots.

The Facebook groups that this information was first posted on included Viper Drivers Only, Viper Pilots Association and the Viper Chicks (female F-16 drivers). These Facebook group sites are still active today. As of Saturday April 7, 2018, **928** tactical pilots that are members of these various groups have responded. In November 2017, a new Facebook group known as Old Fighter Pilots was included.

The following questions were posted on these group pages:

Name of Service Branch

Status of service: Active Duty, Reserves, Guard or Retired

Last Rank

Tactical call sign

Total number of tactical jet hours flown

Type of tactical jets flown

Number of hours flown in each type

Injuries sustained (Y/N)

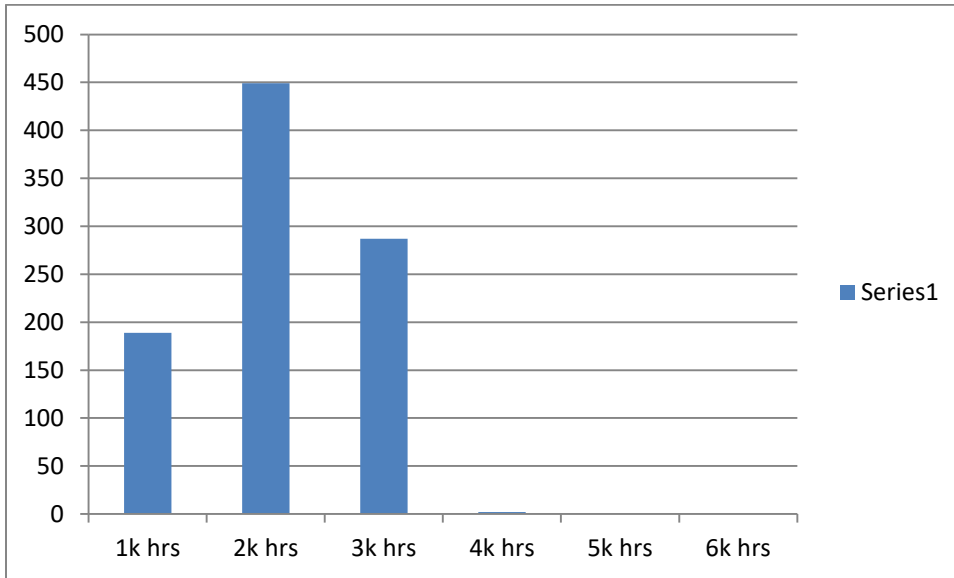
Injury reported to flight surgeon

If retired, apply for VA disability

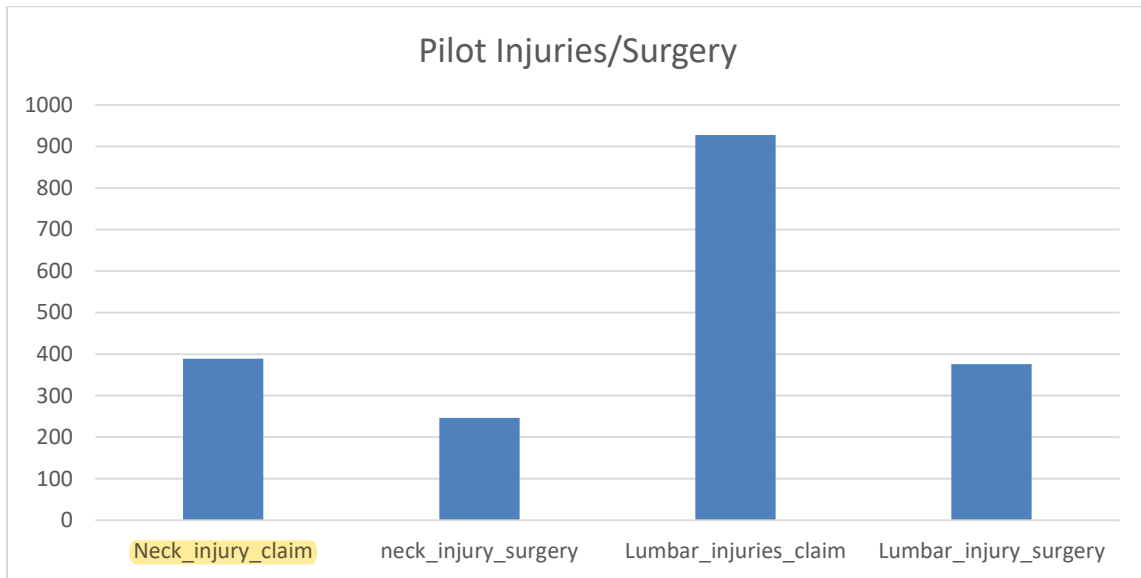
If retired and applied to VA, status of claim

The following represents graphically, data that has been collected from the survey **928** respondents.

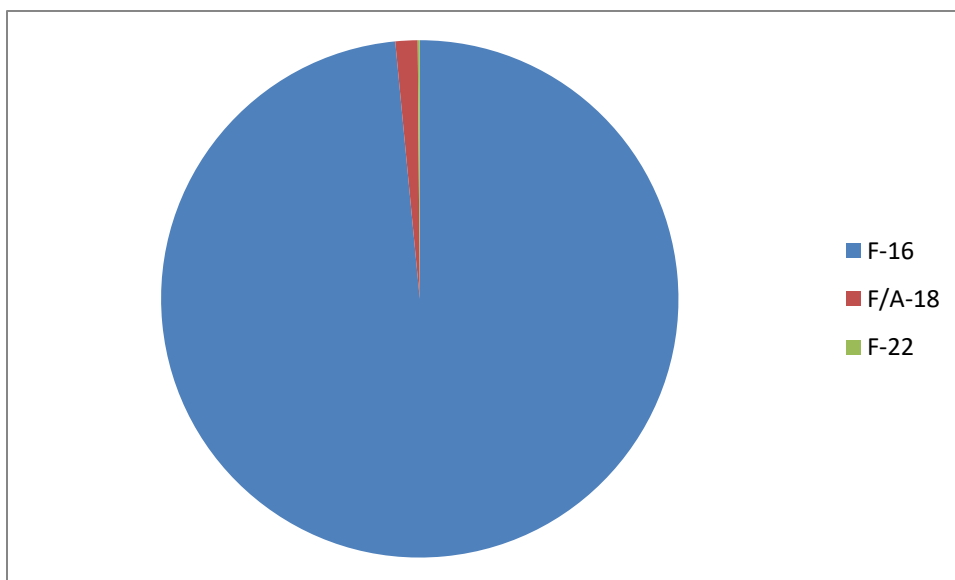
Average Tactical Jet Flight Hours by Survey Respondents



Survey response - Cervical or Lumbar injury claim & if surgery was required



Survey Response - Type of Jets Flown



What gets broken in the long-term

According to [Medical News Today](#), “Repetitive Strain Injuries (RSI) covers a range of painful and uncomfortable conditions of the muscles, tendons, and nerves due to repeated or overuse.” (Medical News Today, “Repetitive Strain Injuries (RSI) Explained”, Newman, Tim January 2018)

Add to RSI the extreme compression of the vertebra and disks in a pilot’s neck and lower spine, the foundation for compromised fighter pilot health is formed.

We have included a Korean study (Appendix IV) which we believe is the clincher. **It separates injuries occurring in the general populace from the injuries incurred by fighter pilots.**

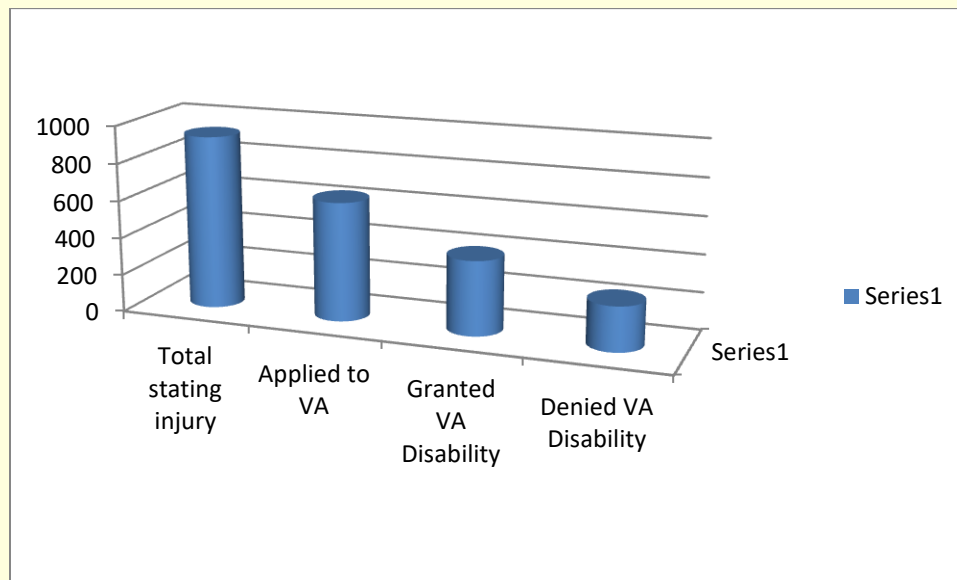
And there are more studies, both in military agencies and by private entities.

How many injured survey pilots were denied a disability rating from the VA

You have read about the physiological dangers faced daily by fighter pilots. You should have an understanding of the type of flying situations faced daily and weekly by fighter pilots and the stresses on their anatomy.

Of the 928 pilots responding to our non-official survey, ALL stated that they had some type of RSI or compression related neck, spine or both injuries.

Many of the pilots are still flying today either in the military or for a commercial airline. Many have retired and applied for a disability rating from the VA. The following graph shows the number that have applied and the number that have been denied due to lack of service related line-of-duty medical documentation.



The numbers for the graph are:

The VA denial rate averages 37.5% of those who apply for a disability!

What can be done

Members of the US House of Representatives and US Senators should work with their committees that help set policies at the VA. These committees should ask the authors of this report, representatives from the Disabled American Veterans, Reserve Officers Association, Military Officers of America Association, Veterans of Foreign Wars, Tailhook Association and the Red River Valley Fighter Pilots Association, a/k/a River Rats, plus professional associations of former flight surgeons, Radiologist associations and even anesthesiologist associations to testify at their committees pertaining to this subject.

The authors of this report feel it is simply unconscionable for the VA to deny service members a disability rating due to said member not having service related documentation to support their claim.

In closing, note that both the Reserve Officers Association and the Military Officers of America Association have created resolutions recognizing this issue and pledge to work with Congress to resolve it.



Appendix I- Medical Studies – COL Roger Kemp, M.D.

There is little need to cite the voluminous stack of studies in the private industry. Carpal tunnel, tennis elbow, Tommy John, whiplash injuries, and football concussions are well known injuries that cause debilitating and crippling body degeneration later in life.

Segments of studies on fighter pilot injuries

The following are excerpts from various military agencies.

Detailed description of RSI during fighter aircraft maneuvers>>

Repetitive strain [RSI] leads to weakening of the ligaments of the spine by stretching and tearing of the ligament's substance along its course and at its attachment on bone. (Any joint for that matter). This laxity then is transmitted to the facet joints which begin to Hypertrophy (thicken and enlarge) to compensate for the repeated shearing stress. This shearing force is also transmitted to the annulus surrounding the disc. These start as micro tears (annular tears) that gradually enlarge or abruptly herniate allowing the gelatinous nucleus pulposa to bulge, protrude, or extrude into the spinal canal compressing the nerve root and or the cord. This repetitive stress also causes bleeding into the ligament at the point of tearing. The cell walls of the RBCs breakdown leaving calcium deposits in the points of tearing. These gradually elongate into spurs (spondylosis) as the ligament tries to preserve its attachment on bone. The instant on and off Hi G's accelerates that process. The focal points of this stress are C5-6 and L4-5 of the spine.

These forces, and attendant injuries, occur on EVERY flight maneuver!

Aviation Space Environ Med. 1989 May;60(5):445-56, author Schall

Non-ejection cervical spine injuries due to +Gz in high performance aircraft.

The potential for significant neck injuries exists in today's high performance fighter aircraft. The G-loads required to produce injury need not be excessive, nor is experience level necessarily protective. Eight cervical spine injury cases, due to or aggravated by +Gz in F-15 and F-16 aircrew members are reviewed. These include two compression fractures (C5/C7), three left HNP's (C5-6/C6-7), one fracture of the spinous process (C7), one interspinous ligament tear (C6-7), and one myofascial syndrome (C6). Mechanisms of injury and evaluation are discussed. Exercise conditioning may play an important role in prevention and protection. The role of screening X-rays and improving equipment remain as areas where further work needs to be done.

We have empirical data from “face-to-face” interviews with OVER 925 retired F16 fighter pilots, plus some from legacy aircraft, including naval pilots suffering from repetitive carrier landings.

Finnish Air Force Study

Cervical Loading Analysis of Fighter Pilots

Studies on cumulative loading,
contributing factors and interventions

Acta Universitatis Tamperensis 1906
Tampere University Press
Tampere 2014

The aim of the studies presented in this dissertation was to study the degenerative changes in the cervical spine due to high Gz exposure; some suggested contributing factors on the neck muscle strain under Gz; and effects of certain countermeasures in reduction of strain under Gz.

Untreated Minor Overuse Injuries Can Become Major

- Health Star Clinic | < Back, Archive | Copyright © 2010 Health Star, Inc
-
- Almost any ongoing, repetitive irritation, stress, strain, sprain, physical tension, prolonged tautness, or pressure can produce an overuse injury to any involved part of the body.
- A repetitive activity as simple as painting walls or ceilings can bring on overuse injury. Such injuries are called bursitis, tendinitis, myositis and other inflammations depending on the tissues involved.
- OVERUSE INJURIES PAINFUL
- Such injuries come across surprisingly painful, tenacious, crippling and sometimes resistant to treatment. That's why chiropractic doctors worry about those of us who repeatedly put our mobility and musculoskeletal health in jeopardy through high-intensity, ongoing, repetitive motions while at play or work.
- WORK AND SPORTS BRING ON INJURIES
- Though an astonishing number of exercise and sports-related overuse injuries occur every day to aerobic exercisers, gymnasts, joggers, swimmers, tennis players, bowlers and other energetic sports persons, work generates numerous overuse injuries, too.
- Early on, if the activity causing the irritation and inflammation is halted soon enough, the body's healing power will usually bring the tissue back to its normal pain-free state. But if the repetitive activity causing the inflammation and pain continues unabated, genuine overuse injury is bound to come and may require chiropractic care.

Almost any ongoing, repetitive irritation, stress, strain, sprain, physical tension, prolonged tautness, or pressure can produce an overuse injury to any involved part of the body.

Appendix II – Additional Research

Occupational Safety and Health Research Institute, Kosha, Incheon, Korea

REVIEW
Occupation & Environmental Medicine

JKMS

DOI: 10.3346/jkms.2010.25.S.S77 • J Korean Med Sci 2010; 25: S77-86

Characteristics of Work-related Musculoskeletal Disorders in Korea and Their Work-relatedness Evaluation

Work-related musculoskeletal disorders (WMSDs) are a type of functional disorder caused by external factors such as occupational repetitive movements, overexertion, awkward postures, and vibration. The accumulation of minor injuries on tissues can lead to musculoskeletal disorders (MSDs). The body parts commonly affected are the waist, neck, shoulders, arms, and wrists.

Work-related musculoskeletal disorders (WMSDs) can be compensated through the Industrial Accident Compensation Insurance Act. We looked at the characteristics of WMSDs in worker's compensation records and the epidemiological investigation reports

WMSDs by the OSHRI accounted for 65.6%. Ergonomic and clinical characteristics were associated with the approval rate; however, the degenerative changes had a minimal affect.

Welfare Service. We presumed that there were perceptual gaps in work-relatedness interpretation that resulted from the inequality of information in ergonomic analyses. We propose to introduce ergonomic analysis to unapproved WMSDs cases and discuss those results among experts that will be helpful to form a consensus among diverse groups.

All Ergonomic issues

There are three criteria for approving compensation claims for WMSDs under the *Industry Accident Compensation Insurance Act* (IACI Act). On a basic level, work based activities that repetitively places stress on the body that results in a MSD in a specific part of the body should be identified. Second, there is a

The variable that greatly affected work-related evaluations was the ergonomic analysis result. Most epidemiologic investigations held that ergonomic results were the major factor behind a decision. In fact, there was a strong association between the ergonomic analysis results and work-relatedness evaluations ($P < 0.01$, chi-square test). The OSHRI approved 71 of 79 cases as musculoskeletal burden work. The unapproved cases were 5 of 32 cases and showed a considerable difference (Table 4).

Of the 127 cases, there were 94 cases (74.8%) in which age and degeneration were not mentioned as a cause in the final paragraph of the study. Among the 32 cases that mentioned age, there were 9 cases where they could not be differentiated by a degeneration level adjustment for age, instead in estimating it was more probable that the work factors effected early degenerative changes in lesions and approved the work-relatedness designation.

NB: Ergonomic issues

Age degeneration not mentioned.

Ergonomic Assessment Tools

The OSHRI used a variety of ergonomic tools and one or more ergonomic tools were used in 81 cases out of the 127 epidemiological investigations. The Rapid Upper Limb Assessment Tool (RULA) was most frequently used in neck disorders. Of 29 cases where RULA was used and in 17 cases it was used to assess neck disorders. When RULA was applied to neck disorders, a method of evaluating part of the neck separately (according to the angle of flexion and the extension of the neck scale) and a method of evaluating the total action level were used. A score of 5 or higher was given for neck flexion and an extension of 20° degrees or higher; this was used as the criteria of ergonomic stress.

The Rapid Entire Body Assessment Tool (REBA) is an ergonomic tool that is used most frequently next to RULA. REBA, a work posture evaluation tool, was developed to complement RULA, which is limited to its coverage of the posture of the upper limbs. Lee et al. (2) reported that REBA was the most appropriate tool for evaluating systemic postures. The subjects showed an irregular work posture in all of the 17 cases that used REBA.

The Strain Index (SI) is a quantitative assessment technique for upper limb disorders originally developed at the University of Wisconsin (3). It calculates the SI as a product of the pinch/grip power, duration, frequency, posture, work speed, and work-

NB; Specific tools used consistently, as opposed to “manual” evaluation

For vibration measurements, there was 1 case involving a local vibration measurement and 5 cases involving systemic vibration measurements. The National Institute for Occupational Safety and Health (NIOSH) reported in 1997 that vibration was very closely related to hand-arm vibration syndrome and lumbar pain epidemiologically; however, it reported an insufficient epidemiologic basis for cervical pain. Of epidemiologic investigation cases, there were 2 vibration measurement cases of a ruptured cervical disk (1 case approved and 1 case unapproved), 1 case of lumbar disc herniation (approved), and 2 cases of combined ruptured cervical disk and lumbar disc herniation (1 case

NB; NIOSH is referenced in other studies.

In addition to these tools, the OSHRI used for Ovako Working Posture Assessment System (OWAS), NIOSH Lifting Equation (NLE), American National Standards Institute (ANSI) Z-365, biomechanical loading analysis, surface EMG, and other similar tools that consider various work conditions and work environment conditions.

Neck and upper limbs disorders

There were 99 cases of neck and upper limb disorders out of the 163 cases. Investigated in more detail, the neck (40 cases), shoulder and shoulder joint (27 cases), and simultaneous involvement of the neck, shoulder, and upper arm (4 cases); while the wrist

NB; wrist, hand, knee ARE generally NOT an issue for pilots!

Herniated cervical disc: A degenerative change of the disc by natural aging and degenerative changes precipitated by mechanical factors cannot be differentiated. Specifically, work-relatedness cannot singularly be determined by a diagnosis of disease, but by the level of the effect of which risk factors in the workplace can be attributed to harming the disc. Occasionally in the event of the findings of early degenerative changes that occur sooner than normal at the same age we can estimate such a clinical finding as work-related. It is reported that soft disc herniation may occur generally in the 30s-40s and that hard disc herniation may occur mainly in those over 50s. This herniation can be accepted as a work-related factor for this disease if some people suffer from one of these diseases before the age at which it occurs most commonly; however, degenerative changes of

cases, COMWEL presumed the worker to be exposed to an acceptable musculoskeletal burden; however, this case was also rejected due to the presumption of degeneration by natural aging. Instead of regarding the existence of a musculoskeletal risk factor for a worker (positive proof that such a progress could exist was a first-order priority) they gave greater priority to the MRI finding (negative proof that there can be no such progress). It remained the degeneration differentiation was an unsolved uncertain problem. We assumed it as a type of decision-making process problem. In 11 cases involving degeneration findings,

The variable that greatly affected work-related evaluations was the ergonomic analysis result. Most epidemiologic investigations held that ergonomic results were the major factor behind a decision. In fact, there was a strong association between the ergonomic analysis results and work-relatedness evaluations ($P < 0.01$, chi-square test). The OSHRI approved 71 of 79 cases as musculoskeletal burden work. The unapproved cases were 5 of 32 cases and showed a considerable difference (Table 4).

NB; Analyses and measurements ALWAYS pointed to ERGONOMICS, not OLD AGE.

The equality of opportunity is universally important and we think that the present worker's compensation system has a significant defect in the ability to classify work-relatedness issues. For solving this problem, we try to guarantee the epidemiological investigation that includes ergonomic analysis in all unapproved cases and we try to form a consensus among experts about this subject. For that goal, we must start to introduce a training system that can evaluate work-relatedness issues. Simultaneously, we need to evolve the quantitative explanations for the attributions of musculoskeletal burdens.

CONCLUSIONS:

Age is NOT the major, or even minor, contributor to retired fighter pilot injuries!

At least this article's recommendation is: "start to introduce a training system that can evaluate work-relatedness issues using the tools in this article."

Appendix III – Surveyed Pilot Comments

Note: Due to the sensitivity of this material, many pilots asked for their personal identification to be blocked. Where pilots did consent, we agreed to show just their rank and tactical call sign or first name

LtCol Yoda – 4700 Hrs, F-16 - I would like to be included in your actions and information for former high-performance fliers and their spinal problems. Like most, had issues as I exited the USAF, but was concerned that officially documenting a "disability" would adversely impact my potential future as an airline pilot. Had neck and lower back problems well before I retired, but... (F-4s for three tours, T-37 IP for 4.5 years, F16s for nearly 11.5 - 2700 hours, 4700 hours total) so now I'm paying the price. Chronic problems with the lower 5 vertebrae as evidenced by an MRI. Let me know what I can do to help and please add me to your info list.

BG Lodrag my total military fighter time was 4000+ hours when I last flew in the Air Force. I was recommended for cervical surgery by Bethesda Medical Hospital when I retired in 2007. I underwent a two level lumbar fusion in 2015. I had an LOD for my neck in my military medical records and was still denied by VA for lack of documentation during my military career. I was also denied in 2016 for my lower lumbar.

Cmdr Master 3500 hrs F/A-18 - i have had both a partial laminectomy at C5 C6 and a fusion at L4 L5 S1

LtCol Hunter 3000 Hrs F-16 & F-4. It's funny that I read your post today. I've been in bed for 10 day due to sciatica (they think) in my lower back. Hurts like crazy. I flew F-4s for years, and then the F-16 for a while. The F-16 must be a gen 4 aft, but does the F-4 qualify? I filed several years ago, was turned down. Well past my appeal now. Maybe I should talk to the DAV, give it another round.

LtCmd Harley – F/A-18 -3000 Hrs. L5/S1 fusion

LtCol Toto – 3000+ Hrs F-16. do you guys have some kind of talking paper or points about the VA stuff so that when I write my representatives it will sound slightly more refined than “my back’s all f’ed from riding around in ejection seats for 3,000+ hours

LtCol Parker - fsm viper guy..I saw your post regarding va claims and dealing with the va..I filed a claim in 15 and it was denied..have sat on it and my ny resolution is to refile and get this deal done..my neck is jacked like most viper guys..couple of questions 1. My claim was denied in 2015 so its been over 2 years..do I just need to refile this snce apeal window is closed? I started out in Hogs at Grissom rserve, and migrated to vipers in Fort Smith where I retired in 2012

LtCol Timber -Yes. I would love to get involved. C-model driver. Active Retired. Flying part time with Guard to help out experience levels (on/off status as required to fly). I even reported a fuge related injury while active and still no love. Let me know what I can do. Thanks for the fight and let me know where I can help. We also have a flight doc at NOLA that has taken spine injuries as personal endeavor if you need "doc" inputs.

LtCol Chico – 1000 hrs F-16, 2700 hrs total military. I'm on a traction machine with dry needling weekly just to triage the neck. With the addition of the HMCS, I know the neck loads are higher and guys will get injuries earlier

LtCol Chief - 21 years in, flew F-15C for 14 years and finished in the QF-4 for 3 years. Didn't really know what I was doing when I retired, but gave a copy of my medical records to VA representative as part of retirement outprocessing. Ended up getting 10% for Thoracolumbar spine strain, and 10% for degenerative disc disease of the cervical spine. No idea how, but I did force the USAF to give me MRI of neck, upper and lower back before I retired and provided these to VA as well when I retired in 2011. Turning 50 this year and on each birthday, I can feel the neck and lower back a little bit more. I have not visited a VA hospital since my initial in processing to the system (which was a horrible experience in and of itself!). I hope this helps your effort and if you need any other information from me, let me know. I want to go back to the VA as the pain increases, but not sure where to even start.

LtCmdr Snyder – F/A-18, something was up with my lower back but kept my mouth shut so I could get a job with the airlines. Anyway, the month I left a disc ruptured at L5-S1. Several others were bulging. I never had surgery and it doesn't bother me too much. About 5 years ago my arm started burning. Several bulging discs in my neck. The VA decided not to file a claim for the back as I had no documentation. I did get 10% for hearing loss and tinnitus.

LtCol Pete, The VA said, anything you claim, must be in your medical records. Ofcourse when you are flying, you or the flight surgeon try to avoid putting stuff in writing, or being DNIF. I got lucky, they found a comment I assume, that I had complained about my lower back which I over Ged just a few times. The VA in down town Miami was horrible the first time I tried to just file a claim. I was pretty much thrown out the door. Then I moved to the SW Florida area, and met a guy from the St Pete VA office, he handed me a package to fill out, and off it went. It took years, but I got 10%. Still have constant daily lower back pain. I have an appeal for a couple other things in the works for at least 7 years.

Maj Rodney, Viper driver. 1983 - 1987. Neck and back troubles, Haven't applied for anything. Chiropractor thought I'd been in a bad car crash with my neck. Haven't. Just pain once in a while

Maj Frank, I have disability for my neck. However I want to make this easier for my brothers who never reported their issues while on active duty. We need to get this DONE. I live in DC area and know my way around the Hill. I'll be glad to lobby and visit members when appropriate

LtCol John, didn't want to jump into your feed, so decided to IM you... I also have extensive back problems and managed to get 40% from the VA for those. More importantly, about 3 years ago I developed congestive heart failure (CHF) with a slew of heart related myopathies (A-FIB, A-Flutter, etc.). I have no history of heart disease anywhere in my family and I had/have zero arterial blockage in my system. My cardiologist stated that he believes he is seeing an increase in these types of symptoms from retired fighter pilots that were exposed to the high-g environment over long periods of time. In laymen terms, G's stripped the "wiring" out of my heart. I'd be curious who else in this group might have developed these kind of issues. After 3 heart procedures, 8 electro-cardiac shocks and 6 minutes of CPR, I wouldn't wish this on anyone!

LtCol Ed, Add to the back injury discussion... and thanks for pressing with this. I retired 6 months ago after 20 years in the A-10. I received a disability rating, which included a denial for back pain, even though that is my single greatest problem. Just like in your post, denial was due to lack of documentation. I'm going to start an appeal after visiting a civilian doc in the near future.

CMD Norris here (62). Naval Aviator and USAF exchange pilot (20 yrs) - F-14, F-15, F/A-18s. Turned down for VA disability last year. I do have 60% VA disability including cervical spondylosis. Please add me to your posse and let me know how I can help. Thx!

LtCol Nathan, I'm very interested in your efforts to have back pain addressed by the VA. I've had a number of problems over the years, requiring numerous visits to chiropractors and massage therapists. I put in for it when I retired, and the VA assigned me a 10% rating for lumbar degenerative disc disease. Seems a little low to me. I agree with you that anyone who has flown fighters for years ought to have a presumption of injury to the lower back/cervical injuries.

Comments where respondent asked for identity to be withheld:

- 1.) I have had both a partial laminectomy at C5/C6 and a fusion at L4/L5/S1. 3500 hrs F/A-18 & 1200 hrs A-7" I was active duty from 1980 to 2000 retired Sept 2000. I started flying the Hornet in 1987 had lower back issues that I NEVER told anyone about, club foot, sciatic issues etc. In 1997 I severally ruptured a disk at the C5 C6 level while flying 5% award. I saw a pain management specialist 3-4 times over the years post retirement and had 3 epidurals for pain.
- 2.) The lower back issues that started in 1987 got progressively worse over the years, I managed it with inversion traction at home. In the spring of 2017 the pain could no longer be managed by inversion so I began seeking medical treatment. I was diagnosed with Spinal stenosis, spinal spondylolisthesis, herniated disks and a broken facet. I had surgery in Jun 2017 that resulted in a fusion at the C4 C5 and S1. My doctor said the condition of my lower spine was horrible and the result of repeated trauma certainly like what I described to him I experienced all those years in fighters
- 3.) The lion share of our injuries involve our necks and lower spines a typical high G turns in a fighter. The aircraft is on a knife turn causing the force of gravity to load up to about 9 Gs. That is sustained for several seconds. Also note the pilot's head being raised up and looking over the shoulder. What that causes is a twisting, again while the body is being compressed at nine times the normal weight. This is just a snapshot of an event that may last up to 30 minutes going from side to side. Always banking, yanking and turning. training, such is referred to as a BFM sortie. Those are where we practice aerial combat, a/k/a dogfighting. I have endured

- two major 4hour surgeries since my back decided to break back in August 2015. After my first surgery, I applied to the VA for a disability and was denied within a week due to lack of line-of-duty related medical documentation.
- 4.) The pilot's head and torso do not conform to the seat angle. To fly a high performance aircraft, the pilot must be oriented physically in such a way that his head is aligned with the vertical axis of the aircraft as a starting point. Once so oriented, he can turn his head, and even look back over his shoulder, but always he has that base of attachment to the aircraft to maintain orientation to the aircraft, the bend in his thoracic spine yields a net angle less than the 30 degrees comfortable. But in maneuvering flight, I found it very difficult to adapt did, I don't know. I attribute my injuries in the thoracic spine area to several incidents I had flying the F15, and I attribute all of my lumbar area injuries to events in the F16. That isn't based on science or medical evidence that is just what I believe based on when and where I recall having painful injuries.
 - 5.) Just to let you know I'm not a pilot but served as a USAF Weapons Systems Officer (Navigator by rating) flying behind the pilot in F-4s for eighteen years. I have had many g's put on me while my head was in the scope using the radar or designating laser guided bombs. Also, there were many times I suffered whiplash type g's when not expecting the pilot to yank on the stick. The result of this is one crushed neck, for which I receive claims \$\$\$. The other is moderate to severe lower back pain, which started in the 80's
 - 6.) Took X-Rays and saw that the space between L3 and L4 had slightly narrowed but saw much more narrowing between L4 and L5 with the presence of small bone spurs on L5. That led him to order a myelogram procedure at the hospital where a dye is injected into the spinal column and he and a neurosurgeon watched how the dye traveled as they dynamically moved my torso in bending (in side to side and fore and aft bending modes). The orthopod said he didn't want to do torsional twisting as that might shear off the bone spurs and lead to even worse problems. The next week (September 1966) I had a 5 hours laminectomy and spinal fusion of L4 and L5. The orthopod said L3 and L4 might continue to degenerate but he didn't want to do them both at the same time. Horseshoe-shaped bone washer to do a hard fusion of L4 to L5. He said that they found that using the patient's own bone material.

- 7.) I'll PM you. Neck issues and major L5, S1 issues. Issues from side stick as well. Waiting for VA as well. 2 micro discectomies over the years. L2-L3 and L3-L4. Retired Maj Gen....flew the Viper from 1983 to 2013, both AD and ANG.
- 8.) They changed the reg this summer & it now says you can't fly with a herniated disc unless you have a waiver. I think the regs encourage pilots to hide their back problems instead of getting care early. So at 18 years in, I'm just starting an MEB for my back & neck to hopefully get back in the cockpit (any cockpit). I have 10 discs in various states of disrepair, but 2 neurosurgeons and a neurologist say we shouldn't do surgery (yet).
- 9.) Bulging L5 and slightly bulging L4; not too much of a problem with stretching but no physiological improvement in three years based on MRI and X-ray. Left shoulder chronic bursitis, also manageable with physical therapy. Just started the VA's processes. Herniated Disc C5/6 accompanied with numbness down left arm into fingertips. Nerve damage that caused muscle spasms across entire upper back and neck. Weakness in left arm. Arms above shoulder level caused pain. Had to adjust my entire lifestyle to limit aggravating it. Physical therapy didn't really work. Got an artificial disc put in a month ago and haven't felt this good in years. Hopefully it continues and I'll get back to where I was. I did get 70% on the way out. Opted to have my personal doc and not the VA do the surgery to avoid the quagmire that is the VA healthcare. I could have had them do it all for free.
- 10.) Ruptured L4/L5 here. Had a micro discectomy that fixed it for a while. After getting back in the jet it re-ruptured and I had to have it fused.
- 11.) I have a herniated disc between c5/c6 or maybe c7 I don't remember exactly. All I know is it a constant pain. I've had injections, and they didn't work. Pain in my arm and under my collar bone that had mostly subsided with physical therapy one of the MAIN issues is lack of support from flight Med. I'm still flying, and **99% of the "experienced" dudes in my Reserve squadron have back/neck issues**. We cannot address these while flying unless it's legitimately debilitating because instead of working with us, flight Med tells us we are disqualified from flying.

- 12.) I was just randomly told I was DNIF from higher-ups in Reserve flight Meds because I got acupuncture from a flight doctor! at my base for back and neck muscle problems. It's the only way I can make it through the BFM phase and still have quality of life...why does this happen? It makes us suck it up (STs) until the end...then the VA can blame it on "advanced age" and not attribute it to 20 years of pulling Gz.
- 13.) The best advice I received and want to pass on is to document your injuries before you separate/retire. Shaw had a great program otherwise I'm sure my back, shoulder and neck injuries wouldn't have been documented. The key is to document what you have before you leave active duty (MRIs, X-rays, etc) so when you are 45,50 or 55 and things get worse; it's already a documented injury on active duty. Flew Vipers from 1995-2016. 2000+ hours. I have taken: Flexural, Celebrex, acetaminophen, Robaxin, Motrin..... Years of chiropractors, 2000-2016. Physical therapy 2015-2016. Right shoulder pain. Tendinopathy. Elbow pain. Sharp/burning pain when elbows pressed on any surface. Right and left forearm and wrist pain. Severe back pain. Bilateral PARS defect (L5-S1) / Disc herniation/ spondylolisthesis / central canal stenosis / arthritis / nerve root impingement - burning in toes and numbness in lower back and right hip and right foot. Neurosurgeon recommends surgery. Bad neck pain. Disc herniation / arthritis / Spondylosis / limited motion

Appendix IV – A Smoking Gun?

Court Rules Chronic Pain Is a VA Disability

[Military.com](#) 6 Apr 2018 By Jim Absher

A [recent ruling by the U.S. Court of Appeals for Veterans Claims](#) may have a major effect on the outcome of many veteran's disability claims.

On April 3, the court ruled that pain, without any underlying disability, may be a valid reason for awarding [VA compensation benefits](#).

Injury Occurred While On Active Duty

The ruling is a result of Gulf war veteran Melba Saunders, who served in the Army from Nov. 1987 until Oct. 1994. Saunders suffered a knee injury while in service and was treated by military doctors and diagnosed with "patellofemoral pain syndrome, " according to Web-MD that is also known as "knee-pain."

She filed a disability claim after leaving the military and was denied, the story is long, but the VA eventually denied her claim, saying "patellofemoral pain syndrome...is productive of no ascertainable impairment." In English that means that her injury, while it was painful, was not an impairment, and therefore not a disability.

All this means is that the VA said she had no real disability, there was no injury that qualified her for compensation. To the VA pain, in and of itself, was not a disability.

Court Says A Disability Doesn't Necessarily Have To Be A Diagnosed Injury

The law (38 U.S.C. § 1110) says that VA shall award compensation benefits "for disability resulting from personal injury suffered...in line of duty."

The law doesn't tell the VA to award compensation for an injury, but for the disability caused by the injury. That is why if you have a greater disability, you normally have a lesser potential earning ability, or lesser enjoyment of life than someone with a lesser disability; therefore you are awarded a greater compensation for that disability, to make up for your reduced earning ability, etc.

The court cited the definition of a disability as "an impairment in the enjoyment of life or earning ability". The court said that "pain is a form of functional

impairment." So the pain can be considered a disability by itself, without any diagnosed injury.

Court Referenced Gulf War Veterans

The court also cited the VA's awarding of compensation benefits to [Gulf War veterans who suffer from "undiagnosed illnesses."](#)

If the VA can pay compensation to Gulf War veterans who have no specified medical condition and suffer from medical issues affecting their life; veterans who have no specified conditions and suffer from chronic pain should likewise be awarded compensation.

What This Means To Veterans

While that isn't exactly clear, the VA hasn't issued a statement on the ruling, if you have chronic pain as a result of your military service, you may want to sharpen up your pencil and look at filing a claim.

To do it right, we always recommend using a [Veterans' Service Organization](#) to help you, since they are adept at battling the VA, and don't charge you for their help.

Appendix V – Addition Medical Research – Brigadier General Duane Lodrige, USAF (ret)

Below is a comprehensive summary of professional studies, several are PhD or Masters Theses. This list includes aeromedical studies from no less than 18 different Air Forces worldwide. The literature substantiates that the severe neck and lumbar injuries suffered by fighter pilots are caused by both acute and long term repetitive exposure to a high +Gz work environment.

1. National studies which quantify the high incidence of cervical pain and injury in the fighter pilot community worldwide:

- Study showed that 40% of Finnish fighter pilots experienced in-flight neck pain during the first one to three years of their flying career.
- Modern air combat developments and their influence on neck and back pain in F-16 pilots: (Aerospace Medicine and Human Performance; Thoolen et al, Nov 2015.) Neck and back pain in fighter pilots remains a serious occupational problem. The prevalence of reported neck/back pain in Dutch pilots has increased 280% in ten years.
- +Gz-induced neck injuries in Royal Australian Air Force fighter pilots: (Aviation, Space, and Environmental Medicine; Newman, 1997). 85% of Australian F-18 pilots reported some form of neck injury due to high G maneuvers.
- A comparative study of G-induced neck injury in pilots of the F/A-18, A-7, and A-4: Aviation, Space, and Environmental Medicine; Knutson et al, 1998. Study reported that 74% of F/A-18 pilots suffered acute neck injuries during their flying careers and more than 50% suffered a major neck injury.
- G related musculoskeletal spine symptoms in Japan Air Force F-15 pilots: (Aviation Space Environmental Medicine; Kikukawa et al, 1994.) 89% of Japanese F-15 pilots reported spinal pain.
- Low back and neck pain of Japanese Air Defense fighter pilots: Japanese Nat'l Defense Medical Journal; Yoshihara et al, 1998. 73% of Japanese F-15 pilots reported flight related neck pain versus 4% of cargo pilots.
- (Neck pain in F-16 vs Eurofighter Typhoon pilots: Aerospace Medical Human Performance; Verde et al, Apr 2015.) There was a significantly

higher incidence of reported neck pain by F-16 pilots (49%) vs Typhoon pilots (6%).

(Back Pain and its consequences among Polish Air Force Pilots flying high performance aircrafts: Military Institute of Aviation Medicine; 2014). Study showed significant problem regarding spinal conditions in Polish Air Force pilots.

2. High +Gz air combat maneuvers place extreme loads on the soft (muscles and ligaments) and hard (disk and bone) tissue of the cervical spine

Cervical (Loading Analysis of Fighter Pilots: University of Tampere, Finland; 2014.) Study showed that 40% of Finnish fighter pilots experienced in-flight neck pain during the first one to three years of their flying career.

Modern air combat developments and their influence on neck and back pain in F-16 pilots: (Aerospace Medicine and Human Performance; Thoolen et al, Nov 2015.) Neck and back pain in fighter pilots remains a serious occupational problem. The prevalence of reported neck/back pain in Dutch pilots has increased 280% in ten years.

+Gz-induced neck injuries in Royal Australian Air Force fighter pilots: (Aviation, Space, and Environmental Medicine; Newman, 1997). 85% of Australian F-18 pilots reported some form of neck injury due to high G maneuvers.

A comparative study of G-induced neck injury in pilots of the F/A-18, A-7, and A-4: Aviation, Space, and Environmental Medicine; Knutson et al, 1998. Study reported that 74% of F/A-18 pilots suffered acute neck injuries during their flying careers and more than 50% suffered a major neck injury.

G related musculoskeletal spine symptoms in Japan Air Force F-15 pilots: (Aviation Space Environmental Medicine; Kikukawa et al, 1994.) 89% of Japanese F-15 pilots reported spinal pain.

Low back and neck pain of Japanese Air Defense fighter pilots: Japanese Nat'l Defense Medical Journal; Yoshihara et al, 1998. 73% of Japanese F-15 pilots reported flight related neck pain versus 4% of cargo pilots.

(Neck pain in F-16 vs Eurofighter Typhoon pilots: Aerospace Medical Human Performance; Verde et al, Apr 2015.) There was a significantly higher incidence of reported neck pain by F-16 pilots (49%) vs Typhoon pilots (6%).

3. Aeromedical studies that conclude greater exposure to a high +Gz environment causes degenerative disk disease

Viper Neck Health and Exercise Strategies: AF Research Laboratory Aerospace Medicine; Maj Sarsfield, O'Hara, and Wright, Nov 2012.) USAF guidance manual for F-16 pilots regards the significant hazards of high G flight to cervical structures and the importance of proper conditioning.

(MRI findings in the cervical spine of experienced fighter pilots and controls: Aviation Space Environmental Medicine; Petren-Mallmin and Linder, 1994.) Sixteen male experienced male fighter pilots had significantly greater incidences of disk protrusion and osteophytes on vertebral bodies compared to age/sex matched controls.

(Neck injury in advanced military aircraft environments: AGARD CP-471, 1989.) Fighters pilots who are repeatedly exposed to a high +Gz environment commonly sustain acute injuries to the soft and hard neck tissue and suffer from degenerative spine diseases.

(Relationship between physical fitness, demands of flight duty, and musculoskeletal symptoms among military pilots: Military Medicine; Rintala et al, Dec 2015.) Exposure to +Gz causes degeneration of the spinal structure.

(Functional Assessment of Cervical Spine in F-16> Aviation Space and Environmental Medicine; De Losse et al, May 2009.) Spinal symptoms in fighter pilots are a serious aeromedical problem.

(Spinal shrinkage due to +Gz forces: Aviation Space Environmental Medicine; Hamalainen et al, 1996.) Fighter pilot body height was reduced by high G maneuvering. Spinal compression could result in some form of disk trauma.

(Degenerative changes of the spine of fighter pilots of the Royal Netherlands Air Force: Aviation Space Environmental Medicine; Hendrickson and Holewijn, 1999.) Spinal X-rays for 186 F-16 pilots were compared 128 "low G" pilots. F-16 pilots had a significant increase in degenerative disk disease as compared to non-pilot population.

(Degeneration of cervical intervertebral disks in fighter pilots frequently exposed to high +Gz forces: Aviation Space Environmental Medicine; Hamalainen et al, 1993.) Twelve senior fighter pilots compared with 12 age matched non-flyers were found to have significantly higher disk degeneration in the C3-C5 disks. Other cervical disks also showed greater degeneration in pilots.

(Neck injury after repeated flexions due to parachuting: Aviation Space Environmental Medicine; Makela and Hietaniemi, 1997). Noted that Disk degeneration and severe spondylosis from parachuting are similar to spinal degeneration associated with high sustained repeated G maneuvers in fighter pilots.

(MRI findings in the cervical spine of experienced fighter pilots and controls: Aviation's Space Environmental Medicine; Petren-Mallmin and Linder, 1994). Sixteen experienced male fighter pilots had significantly greater incidences of disk protrusion and osteophytes compared to control same age peers.

(MRI of the cervical spine in high performance aircraft pilots of the Spanish Air Force: 66th annual meeting of Aerospace Medicine; Tejada et al, 1995). Seventeen fighter pilots were compared with 22 match cargo pilots. Data showed more severe spinal disk abnormalities occur at the C3-C6 level in fighter pilots.

(Analysis of radio graphic screening of fighter pilots' cervical vertebrae: Aerospace Medicine Journal; Ziyen et al, 1998). Cervical vertebrae radiographs of 116 active fighter pilots compared to 62 control subjects indicated 47.4% of pilots vs. 22% of controls had spinal abnormalities indicating degeneration. Concluded there is a direct correlation between acute neck injury and degenerative changes of the cervical spine.

(Cervical and Lumbar Spinal changes diagnosed in four-view radiographs of 732 military pilots: Aviation, Space, and Environmental Medicine; Tonga et al, Feb 2004). Researchers found an increased prevalence of vertebral spondylarthritic or spondylitis change in jet pilots.

(Ten year review of permanent grounding and flying restrictions in Canadian Air Force pilots: Aviation Space Environmental Medicine; Van Leusden et al, 1991). 17% were from orthopedic disorders of which 40% were disk disease.

(X-ray study of fighter pilot spines in the German Air Force: Pongratz and Pippig.) German fighter pilots had twice as much spinal disease as pilots in transport aircraft.

(Biomechanics of the cervical spine and its modeling: Harms-Ringdahl.) A report on Swedish Air Force pilots and disk degeneration due to forces relating to sustained +Gz.

Pathological and functional changes of the spinal column in pilots of high performance aircraft: Stupakov et al. Reports that 30% of Russian MiG-29 and Su-27 pilots had osteoarthritis spondylosis of their cervical disks.

(Physiopathology and Pathology of Spinal Injuries: NATO Advisory Group for Aerospace Research and Development (AGARD) AG-250 report, 1982). This publication made several references to spinal injuries associated with high G exposure and concluded that the capabilities of new modern fighter aircraft will make spinal disk arthritis the future disease of combat pilots.

4. Fighter pilot suffer acute spine injuries occur under +Gz loads due to muscle fatigue, joint overload, improper cockpit movement or being caught unaware.

(Neck injury sustained during exposure to high-G forces in the F-16B: Aviation Space Environmental Medicine; Andersen, 1988). A High G maneuver caught a rear-seat aircrew man unawares and resulted in an acute cervical C5-C6 ligament injury and compression fracture.

(Non-ejection cervical spine injuries due to +Gz in high performance aircraft: Aviation Space Environmental Medicine, Schall, 1989). Report on 8 cases of acute spinal injury to fighter pilots from high G exposure resulting in 2 vertebral compressions fractures and 3 disk herniations.

(Cervical herniation in fighter pilots: Reunion Hispano l'usa de Neurocigugia, Lisbon, Portugal; Mestre-Moreiro et al, May 1998). Two fighter pilots with histories of neck pain experienced acute cervical disk herniation inflight.

(Neurotological dysfunctions in rear-end car collisions: Univ of Amsterdam thesis; Kortschot, 1995). Denoted similarities in the mechanisms between cervical spine injuries resulting from rear-end car collisions with those from high sustained repeated G maneuvers in fighter aircraft.

(Neck and back muscle loading in pilots flying high +Gz sorties with and without lumbar support: Aviation Space Environmental Medicine; Sovellus et al, Jun 2008). Fighter pilots frequently encounter neck/back pain; a lumbar support might decrease injuries.

5. Studies show that fighter pilots especially those in the F-16 are subject to low back pain and degenerative lumbar disorders

(Low back pain and low level flying: Thesis; Aghina, 1989). A review of the literature and survey of F-16 pilots revealed a correlation between the 30 degree reclined seat and lower back pain.

(Backache and back discomfort: NATO AGARD CP-378, Oct 1985). Report noted that fighter pilots with and without lower back pain had narrowing of spinal disk spaces caused by repeated +G forces.

(Spinal Injury in Turkish Fighter Pilots: Gulhane Military Medical School; Trubedar et al, 1999). Turkish flight surgeons have recognized a significant incidence of vertebral degeneration of the cervical and lumbar spine in F-16 pilots.

(Spine injuries; 5-yr follow-up: Aviation, Space, and Environmental Medicine; Petren-Mallmin and Linder, 2001). MRI study of low back pain concluded that high performance aircraft pilots are at an increased risk of premature development of degenerative disk disorders as compared to their non-flying peer age group.

(Back Pain and its consequences among Polish Air Force Pilots flying high performance aircrafts: Military Institute of Aviation Medicine; 2014). Study showed significant problem regarding spinal conditions in Polish Air Force pilots.

Appendix VI – Reserve Officers Association Approved Resolution



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RESERVE OFFICERS ASSOCIATION

In-Flight Injuries to Pilots and Flight Crew Members Resolution No. 17-02

WHEREAS, pilots and flight crew members of fighter, cargo and utility aircraft suffer cervical and lower spine injuries while flying on duty status caused by cervical and spinal compression during flight maneuvers; and

WHEREAS, pilots and flight crew members of fourth and fifth generation fighter airplanes routinely encounter 9-g turns and other maneuvers; and

WHEREAS, in the F-16, 9-g turns and other maneuvers are routine, and their effects are multiplied by the reclined F-16 crew seats, which cause a twisting of the neck and spine when the flight crew members are looking back at their "six"; thereby causing the spine and neck to be twisted and compressed simultaneously; and

WHEREAS, pilots and flight crew members on flight status are disinclined to report such injuries to medical personnel until after their retirement from military service, either because their careers require they stay on flight status, or because those injuries don't fully manifest themselves until after retirement; and

WHEREAS, a preponderance of studies with pilots and flight crew members who have flown military aircraft have results that support in the line of duty due to development of acute cervical and lower spine problems causing significant disabilities,

NOW THEREFORE BE IT RESOLVED that the Reserve Officers Association of the United States, chartered by Congress, urge the Congress to require that a presumption of service connection, medical discharge and disability pay be granted by the Department of Defense and Department of Veterans Affairs, as appropriate, to former pilots and crew members who develop cervical or lower spine injuries or disabilities, and that when military records are not available the disability should be resolved as a service-connected disability.

Adopted by the National Council, 23 July 2017
Source: Department of Golden West, 6 July 2017

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Appendix VII – Paratrooper Appeal Granted by VA 2009

Citation Nr: 0944823

Decision Date: 11/24/09 Archive Date: 12/04/09

DOCKET NO. 04- 40 682) DATE

On appeal from the
Department of Veterans Affairs Regional Office in Winston-Salem,
North Carolina

THE ISSUE

Entitlement to service connection for a low back disability,
claimed as low back strain.

REPRESENTATION

Appellant represented by: Disabled American Veterans
ATTORNEY FOR THE BOARD
C. Eckart, Counsel

INTRODUCTION

The Veteran served on active duty from June 1972 to August 1986.
This case comes before the Board of Veterans' Appeals (Board) from a rating decision of February 2004 rating from the Regional Office (RO) of the Department of Veterans Affairs (VA), in Phoenix, Arizona, which declined to reopen a previously denied claim for service connection for a low back disability. During the pendency of the appeal the matter was transferred to the RO in Winston-Salem, North Carolina in October 2004.

A June 2007 decision from the Board disposed of some issues on appeal and reopened and remanded the remaining claims for service connection for a low back disability..
This matter is returned to the Board for further consideration.

FINDINGS OF FACT

1. The Veteran is shown to have served most of his military career in Airborne units, with his military occupational specialties throughout service shown to include that of drill sergeant, platoon sergeant, second sergeant and operation sergeant. His service treatment records reflect that he participated in parachute jumps, including one that fractured his right ankle.
2. The evidence reflects that the Veteran has a current back disability with X-ray evidence of degenerative changes of the lumbar spine and chronic low back pain.

3. The evidence includes a recent VA nexus opinion stating that the Veteran's back disability at least as likely as not was caused by or a result of his military duties which included participating in parachute jumps. No evidence directly contradicting this opinion is shown.

CONCLUSION OF LAW

Resolving all reasonable doubt in favor of the Veteran, service connection is warranted for a low back disability. 38 U.S.C.A.

§§ 1110, 1131, 5107 (West 2002 & Supp. 2009); 38 C.F.R. §§ 3.159, 3.303 (2009).

REASONS AND BASES FOR FINDINGS AND CONCLUSION

The VA has a duty to notify and assist claimants in substantiating a claim for VA benefits. 38 U.S.C.A. §§ 5100, 5102, 5103, 5103A, 5107, 5126 (West 2002 & Supp. 2009); 38 C.F.R. §§ 3.102, 3.156(a), 3.159 and 3.326(a) (2009). In this case, the Board is granting in full the benefit sought on appeal. Accordingly, assuming, without deciding, that any error was committed with respect to either the duty to notify or the duty to assist, such error was harmless and will not be further discussed.

The Veteran claims entitlement to service connection for a low back disability. Service connection may be granted for a disability resulting from a disease or injury incurred in or aggravated by active duty. 38 U.S.C.A. §§ 1110, 1131; 38 C.F.R. §§ 3.303, 3.304. In addition, service connection may be granted for any disease diagnosed after discharge, when all of the evidence, including that pertinent to service, establishes that the disease was incurred in service. 38 C.F.R. § 3.303(d). In order to establish service connection, a claimant must generally submit (1) medical evidence of a current disability, (2) medical evidence, or in certain circumstances lay testimony, of service incurrence or aggravation of an injury or disease, and (3) medical evidence of a nexus or relationship between the current disability and the in-service disease or injury. *Pond v. West*, 12 Vet. App. 341, 346 (1999).

The standard of proof to be applied in decisions on claims for Veterans' benefits is set forth in 38 U.S.C.A. § 5107. A Veteran is entitled to the benefit of the doubt when there is an approximate balance of positive and negative evidence. See also 38 C.F.R. § 3.102. When a Veteran seeks benefits and the evidence is in relative equipoise, the Veteran prevails. See *Gilbert v. Derwinski*, 1 Vet. App. 49 (1990).

The Veteran's service personnel records show that he served most of his military career

in Airborne. His Service treatment records are noted to reveal normal spine examination on entrance examination in January 1972 and his report of medical history revealed him to answer "no" to

whether he had recurrent back pain, bone, joint or other deformity, or arthritis, rheumatism, bursitis. A January 1976 periodic examination is noted to have normal spine. He is noted to have been treated in September 1979 for a parachute jump injury where he fractured his right ankle, but with no mention of any back injury. His separation examination of January 1986 likewise showed a normal spine, with his accompanying report of medical history showing he answered "no" to recurrent back pain.

The first evidence of back complaints are shown in a December 1991 VA examination, where the Veteran reported that he started having pain in his back when he was a drill sergeant. He stated

that he has pain of the right lower back that is sometimes radiating into the right leg, suggesting the possibility of radicular pain. He was diagnosed with a history consistent with chronic low back strain. A November 1991 lumbosacral spine X-ray had no significant pathological findings noted.

A subsequent VA examination done in March 1996 discussed his career as a paratrooper, but made no reference to back complaints.

After filing his current claim on appeal, the Veteran submitted a written statement in March 2004 where he reported injuring his back at Fort Dix, New Jersey in 1977. He also reported that his back had worsened in the past 25 years.

VA records from March 2004 revealed the Veteran to be seen for low back pain, with a history given of back pain since 1977, worse in the past 2 years. Physical examination was negative for significant findings, but X-ray done the same month showed degenerative changes in the lumbar spine more pronounced on L4-5. A May 2004 MRI of the lumbar spine gave an impression positive for degenerative changes at L4-5 and L5-S1. Low back complaints continued to be reported in records from July 2005 where he gave a history of back pain with MRI and degenerative joint disease (DJD) that goes down the back of the right leg.

The report of a November 2008 VA examination included review of the claims file and examination of the Veteran. The Veteran gave a history of being on active duty in the Army from 1972 to 1986 as a paratrooper with 214 jumps. He recalled his low back pain starting when he was stationed at Fort Dix and was a drill sergeant doing physical training. He reported receiving treatment for his back at that time, consisting of conservative treatment and bed rest for a couple of weeks.

He reported he had low back pain for the past 25 years which has affected his ability to work. He had repeated X-rays of the lumbar spine and MRI in 2008 and a physical therapy evaluation of June 2008 which was documented in the record. He had pain

throughout all ranges of motion. The impression from the X-ray was moderate to moderately severe degenerative changes within the lumbar spine. MRI from August 2008 yielded an impression of moderately advanced L4 and L5 degenerative disc disease and L4 degenerative spondylosis.

A November 2008 addendum to the VA examination stated that it is as likely as not that any diagnosis of low back disability is etiologically related to the Veteran's period of service (POS)

due to as a result of his active duty as a paratrooper with active participation in the physical examination requirements with 214 parachute jumps from an airplane. It was reasonable to

account his degenerative joint disease on his daily wear and tear on the affected joints.

The examiner's rationale for this opinion was that there was long term repetitive stress on the trunk

joints resulting in pain and decreased range of motion. The examiner again confirmed review of the service treatment records and VA records in forming this opinion.

Records from 2009 revealed continued problems with back pain. A January 2009 private record again assessed chronic low back pain.

A VA treatment record from April 2009 noted complaints of constant back pain with contentions that his right thigh felt numb all the time and he thought it could be nerve pain related to his constant low back pain. The assessment continued to be chronic low back pain.

Based on a review of the foregoing, the Board finds that service connection is warranted for a back disability shown to include degenerative changes of the lumbar spine and resulting in chronic low back pain and restricted motion. Although no treatment for any back complaints are shown in the service treatment records

and evaluation reports, the Veteran is competent to provide lay evidence of having sustained an injury to his back while performing his duties as a paratrooper in service.

See Jandreau,

His service personnel records further confirm lengthy service with Airborne units and service

that included drill sergeant and platoon sergeant, further bolstering his claims of injury through trauma and physical activities that would tend to injury his back. Thus the lay evidence, bolstered by the service records is competent and credible as to his having injured his back in service.

The evidence discussed above clearly shows he has a current lumbar spine disability with degenerative changes. Furthermore the VA examination of November 2008, which included review of the claims file and examination of the Veteran, directly linked the lumbar spine disability to the Veteran's duties as a paratrooper in service, when it stated that it is as likely as not that any

diagnosis of low back disability is etiologically related to the Veteran's service as a paratrooper. There is no evidence to directly contradict this VA examiner's opinion. Rather the evidence, which includes a history of parachuting in service with at least one injury from landing, and the manifestation of back problems a few years after service, tends to be supportive of this opinion. Accordingly the evidence favors a grant of service connection.

ORDER

Service connection for a back disability with X-ray evidence of degenerative changes of the lumbar spine and chronic low back pain is granted.

CHERYL L. MASON

Veterans Law Judge, Board of Veterans' Appeals

Department of Veterans Affairs

Neck Muscle Strength and Endurance in Fighter Pilots: Effects of a Supervised Training Program

MARIE ALRICSSON, KARIN HARMS-RINGDAHL,
BÖRJE LARSSON, JAN LINDER, AND SUZANNE WERNER

ALRICSSON M, HARMS-RINGDAHL K, LARSSON B, LINDER J, WERNER S. Neck muscle strength and endurance in fighter pilots: effects of a supervised training program. *Aviat Space Environ Med* 2004; 75: 23–8.

Introduction: Cervical discomfort is common among pilots of high performance aircraft. An exercise program was introduced to increase the strength and endurance of the neck muscles. The purpose of this study was to analyze whether coaching or reinforcement strategies by a physical therapist was associated with improvement in neck muscle strength, endurance, and neck complaints in two cohorts of fighter pilots performing regular neck muscle exercises. **Methods:** A reinforced group (RG) of 20 pilots (24–40 yr) at an Air Force base received weekly encouragement to perform their standardized exercise program three times per week. A non-reinforced reference group (NRG) of 20 pilots (23–37 yr) from another Air Force base carried out the same program without any supervision. Both groups performed the training program for 6–8 mo. Before and after the training period, isometric measurements of the neck flexors and neck extensors were performed in both groups. **Results:** After the completion of the 6–8 mo training period, the RG pilots significantly increased their neck muscle strength (flexors: $M = 3.9$ nm, $p = 0.000$ and extensors: $M = 5.0$ nm, $p = 0.001$) as well as endurance in their neck extensors ($M = 53$ s, $p = 0.000$). The NRG pilots significantly decreased both strength ($M = 11.5$ nm, $p = 0.0001$) and endurance ($M = 33$ s, $p = 0.003$) of their neck extensors. Furthermore, the NRG pilots did not show any significant change of their neck flexor strength. No significant changes in the frequency of neck complaints were reported in either group throughout the entire study period. **Conclusion:** The reinforced training program increased the strength and endurance of the appropriate muscle groups. In order to draw any further conclusions concerning reducing neck complaints, a longer observation period with a larger group of pilots might be needed. However, it is likely that there is an individual correlation between strength and endurance of the neck muscles and neck pain, which means that any rehabilitation program should be tailored for each individual.

Keywords: endurance tests, exertion, neck pain, strength tests, training effects.

PAIN AND DISCOMFORT in the neck are common among pilots of high-performance aircraft. Several investigations have shown a high frequency of acute cervical discomfort in pilots exposed to high G-forces (1,2,7,14,15,19). The largest number of acute cervical discomfort cases was reported in a Japanese study, where 89% of Japanese Air Self-Defense Force F-15 pilots reported muscle pain related to flying (14). The frequency of neck complaints among Swedish high-performance fighter pilots has been reported to vary between 29–37% (1).

The cervical spine is extra sensitive when exposed to high G-forces. During flying the cervical spine is often exposed to high G-forces in a combination of rotation,

lateral flexion, and extension (7,9,14,15) of the neck. Since the compressive force induced by the weight of the head, neck, and helmet is increased by the G-force, the load on the cervical spine should be reduced (3–5,7).

The most common neck complaints have been of less severe muscular pain and strain. More severe injuries like fractures, ligament ruptures, nerve compression, and intervertebral disk injuries have also been reported (12,16–18,23). Magnetic resonance imaging (MRI) studies of high-performance aircraft pilots show more frequent degenerative cervical disk changes than in controls (9,22). Electromyography (EMG) investigations show that pilots exposed to high G-forces over repeated, short periods use close to 100% of their neck extensor muscle strength (5,21).

EMG recordings of cervical muscle strength and endurance while flying high-performance aircraft indicate higher demands on strength and endurance in pilots than in average persons (21). In a Swedish study on conscripts who had had no exposure to high G-forces while wearing a helmet and Air Force pilots, we found that the Air Force pilots were superior to the conscripts regarding strength of the neck flexors and extensors, and in sub-maximal endurance of the neck extensors (1). However, the conscripts were superior to the Air Force pilots in sub-maximal endurance of the neck flexors (1).

Whether high muscle strength and endurance can prevent acute cervical spine discomfort in conjunction with high G-forces is not yet shown (8). Many authors have suggested studying whether strength and endurance exercises could be a preventive measure for people

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TABLE I. AGE, HEIGHT, WEIGHT, TOTAL FLYING HOURS, AND FLYING HOURS/MONTH (H/MO) OF THE GROUPS EXAMINED. N = 54.

Group*	n	Age (years)		Height (m)		Weight (kg)		Total flying time (h)		Flying h/mo	
		M	SD	M	SD	M	SD	M	SD	M	SD
RG	20	29.4	4.5	1.82	5.2	81.1	8.0	1125	615	14.2	4.0
NRG	20	29.4	3.1	1.80	5.1	80.0	6.8	1153	420	12.6	2.2
RG dr-o	10	31.7	4.2	1.83	4.1	79.0	6.0	1210	617	14.2	2.6
NRG dr-o	4	26.0	0.9	1.82	2.7	75.5	4.9	686	272	11.1	1.3

Reinforced training group (RG), reference group (NRG), RG drop-outs (dr-o) and NRG drop-outs (dr-o). n = 54

*RG = reinforced training group; NRG = reference group; RG dr-o = RG drop-outs; and NRG dr-o = NRG drop-outs.

with cervical complaints (5,14,23,24). Good strength and endurance of the neck muscles might contribute to preventing neck complaints in Air Force pilots. Therefore, for some years, a standardized muscle training program has been developed and is available together with photos and written instructions for exercises at all Swedish Air Force bases.

The present objective was to assess cervical muscle strength, endurance, and complaints as an indication of whether the exercises carried out really did give increased strength and endurance. The first study group was located at an Air Force base where the physical therapist took an active, supporting role in encouraging the pilots to perform the training program. The other study group was located at another Air Force base where only the training equipment, including written instructions, was provided. Our aim was to study whether active reinforcement in a group of fighter pilots improved neck muscular strength, endurance, and a reduction in neck complaints compared with a group of fighter pilots who were merely instructed to perform neck muscle exercises on a regular basis.

METHODS

The measurements used were approved by the Ethical Research Committee at the Karolinska Institutet, Stockholm, and the training program was regarded as a quality evaluation. The development stage was approved by the Regional Ethics Committee before routine testing among Air Force pilots. All subjects volunteered and gave their informed consent.

Subjects

There were 54 fighter pilots who were divided geographically into a reinforced training group (RG) from one Air Force base and a non-reinforced reference group (NRG) from another Air Force base, both with similar environments. However, before the first test occasion, 10 pilots in the RG dropped out due to aircraft accidents, change of duty, or absence from training, and 4 pilots in the NRG dropped out for similar reasons. This left 40 male fighter pilots from the 2 bases to participate in the study. Each group consisted of 20 pilots. Age, height, weight, and hours of flying are presented in **Table I**, including the study groups as well as the drop-outs. Analysis of variance (ANOVA) revealed no significant group differences with regards to

age, height, and/or weight at the beginning of the study.

Prior to the start of the present investigation, 10 out of 20 RG pilots and 7 out of 20 NRG pilots reported having had neck complaints within the past 3 mo. Among the drop-outs, 6 out of 10 pilots among the RG drop-outs and 1 out of 4 pilots among the NRG drop-outs complained of neck pain before the study started. An independent Chi squared test showed no significant difference regarding neck complaints among the four groups (RG, NRG, RG drop-outs, NRG drop-outs).

Questionnaire

In addition to the demographic data, the pilots were asked on a questionnaire whether they perceived discomfort/pain in the neck/cervical, thoracic/spine, and/or shoulder/shoulder joint. The frequency of complaints during the 3 mo prior to the start of the study was reported on a scale of 0–3, where 0 = never, 1 = once/a few times over the previous 3 mo, 2 = once/a few times per month, and 3 = once/a few times per week. The questionnaire was answered on two occasions, before the investigation and 6–8 mo later. The analysis of the frequency of complaints was dichotomized to either never (i.e., “0”), or once/a few times over the previous 3 mo, the past month, or per week (i.e., “1” + “2” + “3” combined). Both groups of pilots, RG and NRG, were physically active and were training for an average of 6.5 hours per week all year. However, very few pilots in either group performed any specific exercise for the neck muscles.

Measurements of Muscle Strength and Endurance

Isometric strength measurements of the flexors and extensors of the neck muscles and sub-maximum measurement of the endurance of the neck extensors were evaluated. These tests were carried out in the order described, and are reported in detail elsewhere (1). Testing muscular strength and endurance in this way is part of a larger Swedish Air Force project (5) and is performed regularly, blinded to previous results. A test-retest in order to evaluate the instruments used for measuring strength and endurance was performed earlier, showing very good reliability (1).

Cervical spine isometric flexor muscle strength: The subject sat on a bench with a firm foam pillow (Scandinavian Mobility Physiotherapy, Spånga, Sweden) be-

tween his back and the gymnasium wall-bars (Fig. 1). The arms hung loosely. The knees were bent so that only the tip of the toes touched the floor. The chin was slightly retracted and vision fixed forward and downward. A dynamometer (Salter 235, PIAB, Täby, Sweden) was secured to the wall-bars and fastened to a horizontal sling around the subject's helmet. The length of the moment arm from the bilateral motion axis of cervico-thoracic motion segment C7-T1 was measured from a point on the neck at the level of C7 to the middle of the sling (3). The subject performed two maximum trials, of which the best result was used in the analyses (13).

Cervical spine isometric extensor muscle strength: The subject sat in the same way as for the neck flexors but now facing the gymnasium wall-bars. The contraction was performed as a neck backward extension (Fig. 2).

Cervical spine isometric extensor endurance: Cervical spine extensor isometric endurance was also tested in a sitting position (Fig. 2). With the neck extensors, the subject pulled a load equivalent to 196 Newton (N) on the dynamometer for as long as he possibly could. The level of exertion was assessed every 15 s with the Borg CR-10 scale. The test was discontinued when the subject could no longer maintain the stipulated force. Both groups carried out the strength and endurance measurements at the start of the study and after the training period was completed 6–8 mo later. When recording the measurements, the test leader did not have access to previous results.

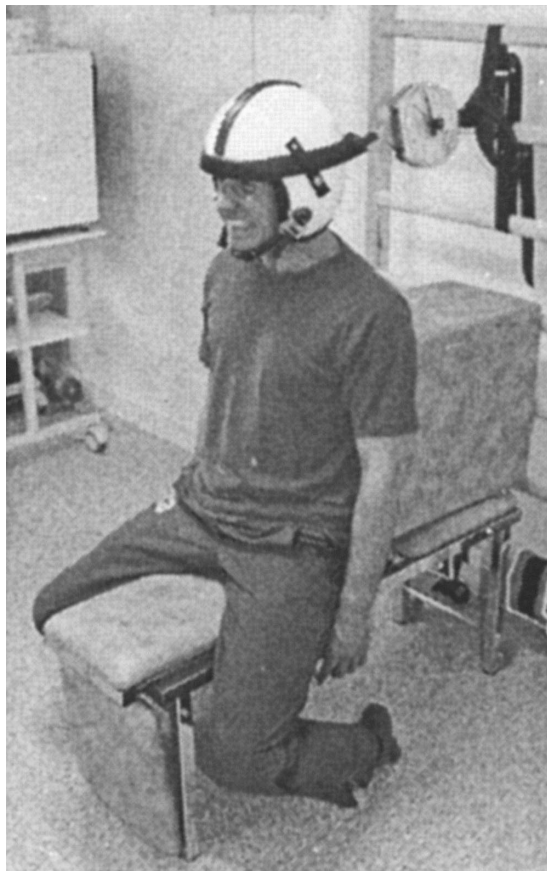


Fig. 1. Test position for measuring cervical spine isometric flexor muscle strength.

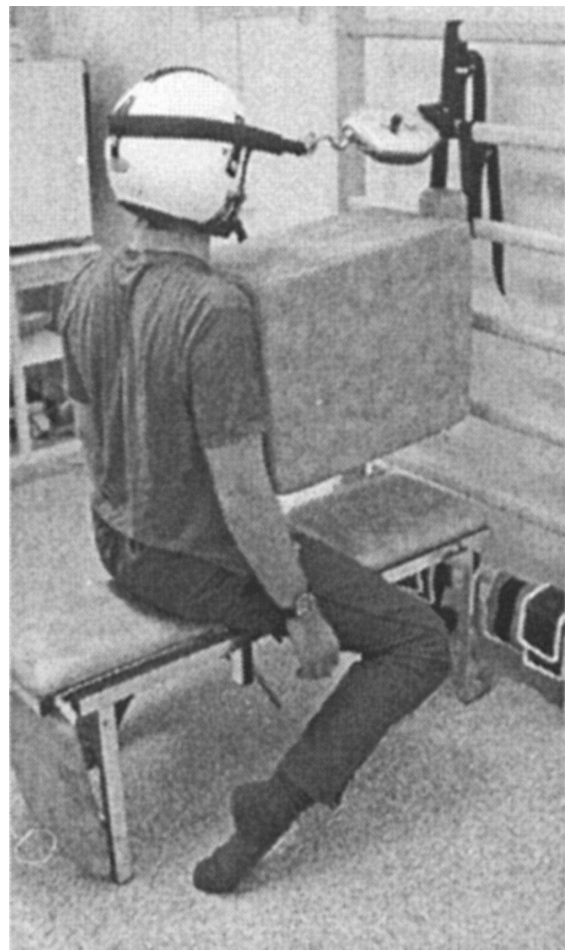


Fig. 2. Test position for measuring cervical spine isometric extensor muscle strength.

Design of the Training Program

The program was comprised of strength and endurance exercises for the neck and shoulder muscles using weights attached directly on the head or on a training helmet in order to give an increased resistance. The weights consisted of 1, 2, and 4 k, and could be combined for additional training resistance. Based on improvements of strength, the weights were increased progressively during the entire training period using 4×10 repetitions each training session. Since many neck muscles are attached to the upper thoracic spine, this region was also exercised for strength and endurance using a rubber tube as resistance. Mobilizing exercises (stretching) for the neck and the thoracic spine region were also included in the program.

The training program for the RG was performed with the help of a pilot who was familiar with the exercises. Thus, this group was coached by him and the local physiotherapist together. They coached the pilots every week via discussions, presence in the training room, and checks of the exercise diaries. The pilots were strongly encouraged to perform the exercises three times per week, and were followed during the whole study period of 6–8 mo. The NRG was left without such coaching support. The training equipment with written instructions was available, but personal training instructions, encouragement to

TABLE II. MUSCLE STRENGTH OF BOTH NECK FLEXORS AND EXTENSORS AND ENDURANCE OF NECK EXTENSORS AT THE FIRST TEST OCCASIONS IN BOTH THE REINFORCED TRAINING GROUP (RG) AND THE NON-REINFORCED TRAINING GROUP (NRG). N = 40.

Group	n	Strength (Nm)				Endurance (s)	
		Flexors		Extensors		Extensors	
		M	SD	M	SD	M	SD
RG	20	38	7.6	56	13.9	68	36.5
NRG	20	45	10.6	70	14.3	118	49.6
Sign.		n.s		p = 0.001		p = 0.000	

perform the program, and exercise diary checks by a physical therapist were not available for the NRG unless requested, i.e., "as usual."

Statistics

ANOVA was used to study whether the groups investigated differed in personal data, number of flying hours, or strength and endurance of the neck muscles prior to the start of the investigation. Differences between the results of the first and the last test occasion were analyzed using the paired *t*-test. Possible group differences with regards to frequency of complaints during the study period were analyzed with an independent Chi-squared test. The significance level was set at 5%.

RESULTS

Baseline data with regards to neck muscle strength (Nm) and endurance (s) from the first test occasion, prior to the start of the study, is presented in **Table II**. Group differences were found regarding both isometric neck extensor strength ($p = 0.001$) and isometric endurance of the neck extensors ($p = 0.000$), the NRG being somewhat more fit than the RG.

Among the 20 RG pilots (reinforced training), 11 pilots carried out the exercises less than twice per week (RG1), while 9 carried out the exercises twice per week or more (RG2) (**Table III**).

Isometric muscle strength of neck flexors and extensors: The pilots of the combined RG (RG1 and RG2) showed increases in muscle strength of the neck flexors ($M = 3.9$ nm, $p = 0.000$) and extensors ($M = 5.0$ nm, $p = 0.001$) when the training period was completed. The pilots of the NRG showed no significant difference regarding neck flexor strength, but a decrease of neck extensor

strength ($M = -11.5$ nm, $p = 0.0001$) after 6–8 mo (**Table III**).

Isometric neck extensor endurance: The pilots of the combined RG (RG1 and RG2) increased the endurance of their neck extensors to 53 s ($p = 0.000$) after 6–8 mo. The pilots of the NRG decreased the endurance of their neck extensors to 33 s ($p = 0.003$) when the training period was completed (**Table III**).

Frequency of neck complaints: The number of pilots with neck complaints during the last 3 mo of the investigation was unchanged in both groups (**Table IV, Table V**). There was no statistically significant difference between the groups in this respect. There was no statistically significant difference either in neck muscle strength or in endurance of the neck extensors between those pilots who seldom or never reported neck complaints and those who frequently reported neck complaints.

DISCUSSION

Good neck muscle strength and endurance in Air Force pilots might act as a preventive measure against perceived neck discomfort. Previous authors maintain the importance of neck muscle training in order to prevent neck injuries (11,14,20). The present study shows that completing an assigned training program of three times a week over a 6–8 mo period to improve neck muscle strength and endurance is consistent with physiological training principles (6,25).

Both the RG and NRG pilots were physically active, i.e., exercised on average $6.5 \text{ h} \cdot \text{wk}^{-1}$ throughout the whole year. However, only a few pilots performed specific exercises for the neck muscles. Other similar studies have usually involved patients with neck pain, but with little or no training experience. Thus, comparing the results of strength and endurance training in fit pilots to non-fit patients with pain is not appropriate. Untrained patients probably have a larger potential for improvements of both muscle strength and endurance and also for a reduction in the frequency of complaints. (6,14,25).

In the present study it was not possible to evaluate whether reducing or increasing the number of flying hours would have influenced the results during the training period. However, earlier EMG studies have shown that the neck extensors are activated to nearly their maximum capacity for repeated short periods during high-performance flight (5,21). The present investi-

TABLE III. MUSCLE STRENGTH OF BOTH NECK FLEXORS AND EXTENSORS AND ENDURANCE OF NECK EXTENSORS PRIOR TO THE START OF THE STUDY AND AFTER 6–8 MONTHS IN THE REINFORCED TRAINING GROUPS (RG) AND THE REFERENCE GROUP (NRG), RESPECTIVELY. N = 40.

Group	n	Strength (Nm)						Endurance (s)		
		Flexors			Extensors			Extensors		
		M	SD	p	M	SD	p	M	SD	p
RG1	11	4.0	3.4	0.003	4.4	6.7	0.05	55	39.0	0.001
RG2	9	3.8	3.2	0.008	5.7	4.8	0.007	52	27.7	0.000
RG1 + 2	20	3.9	3.3	0.000	5.0	5.8	0.001	53	33.6	0.000
NRG	20	-0.6	6.1	0.7	-11.5	10.9	0.0001	-33	43.5	0.003

TABLE IV. FREQUENCY OF COMPLAINTS IN THE STUDIED GROUPS, WITH REGARDS TO MUSCLE STRENGTH OF NECK FLEXORS AND EXTENSORS BEFORE AND DIRECTLY AFTER THE STUDY PERIOD. N = 40.

Group	n	Flexors (Nm)				Extensors (Nm)			
		Before		After		Before		After	
		Md	range	Md	range	Md	range	Md	range
RG c 0*	10	36	35	41	36	53	62	55	53
RG c1-3	10	39	14	41	9	53	18	59	17
NRG c 0	13	45	38	48	39	74	44	58	25
NRG c1-3	7	40	35	38	33	71	45	55	30

*C 0 = No complaints; C 1-3 = frequent complaints at start and during last 3 mo of the study.

gation showed that the training program was possible to accomplish. Pilots who exercised their neck muscles regularly for 6–8 mo under supervision increased their strength and endurance compared with those pilots who were instructed to perform these exercises on a regular basis without supervision. Statistically significant differences were found between the RG and the NRG in maximum strength and sub-maximal isometric endurance of the neck extensors in favor of the RG pilots, who showed improvements to a higher extent.

Due to communication between the pilots, we could not randomize the pilots in each base to two different exercise strategies. For this reason, stronger reinforcement and individual discussions were given to all the subjects at one Air Force base rather than to some pilots and not others at each Air Force base. One weakness of the present investigation was that the NRG was, for some reason, stronger and showed higher endurance levels at the beginning of the study. However, the two Air Force bases involved were almost 1000 km apart and to be able to perform this kind of investigation, we had to have the RG at one Air Force base and the NRG at the other. Furthermore, prior to the study, we did not know about any group differences. This was revealed when we made the statistical calculations and analyses after the study period was completed. An earlier study at an Air Force base in the same geographical area as the RG showed strength and endurance at the same level as in the present NRG at the beginning of the study (1). The present RG had less strength than the NRG, but on the other hand, this group was more homogeneous. The standard deviation in the present study was less than in the earlier study, which means that pilots with extreme values were, for various rea-

sons, absent from the base during the study. During the training period, the strength and endurance increased in the RG by almost 10%, but despite this, the average values were not equivalent to the pilots from the NRG.

The RG pilots were instructed to carry out the program three times a week, but this became much less, due to Air Force drills and in-service training. At the end of the study, the groups were classified regarding training frequency. However, it was difficult to establish an exact group classification since some weeks the pilots exercised more regularly than other weeks. Therefore, the frequency of performing the training program was estimated as a mean value per week over the entire study period. The test occasions at 6–8 mo were adjusted according to the availability of the pilots. The results of the muscle strength of both neck flexors and extensors after 6–8 mo of training showed statistically significant improvements in all supervised training groups irrespective of low training frequency. The NRG had a statistically significant reduction in muscle strength and endurance of their neck extensors after 6–8 mo which, to some extent, might be explained by one pilot experiencing pain after the first test. This information spread among all the subjects in the NRG, and they may have avoided exerting their maximum force in the second strength and endurance test.

Another issue to consider is that the standardized measuring methods are limited regarding the test positions, which makes it difficult to compare different studies of strength and endurance (4,6,25). Our strongest pilots were not the ones with the longest endurance time, and there was a high individual variation. No significant correlation between muscle strength and endurance was found, which might have been expected, as the endurance test was performed at an absolute resistance force level and not related to individual extensor strength. However, the results from the 6–8 mo of endurance training showed a clear improvement in neck extensor endurance in all pilots of the RG.

The neck extensors show the greatest isometric endurance of the major neck muscle groups. However, we have not found any study on prevention of neck pain by performing endurance training of the neck extensors. During the 3 mo immediately prior to the start of the study, 10 pilots in the RG and 7 pilots in the NRG reported complaints in the neck region. The same number of pilots had neck complaints at the end of the investigation. This number may have been too small and the observation period too short to show any pos-

TABLE V. FREQUENCY OF COMPLAINTS IN THE STUDIED GROUPS, WITH REGARDS TO ENDURANCE OF NECK EXTENSORS BEFORE AND DIRECTLY AFTER THE STUDY PERIOD. N = 40.

Group	n	Extensor endurance (s)			
		Before		After	
		Md	range	Md	range
RG c 0	10	64	139	108	165
RG c1-3	10	67	98	116	164
NRG c 0	13	123	148	74	121
NRG c1-3	7	99	115	94	70

See tables I and III for legend.

sible effects with regards to the frequency of complaints due to increased exercise. Another reason could be that all pilots in the present investigation were well-trained individuals exercising, on average, 6.5 h·wk⁻¹. Their general good physical condition might mean that they already had relatively good neck muscle strength at the start of the study despite not having carried out any specific neck muscle exercises.

It has been previously reported that neck complaints can be reduced after training periods with intensive strength and endurance exercises between 3–8 wk (6,16,25). However, it should be pointed out that these three studies did not include any control groups. Furthermore, these subjects might have had less neck muscle strength than the pilots in the present study. It is also most likely that the correlation between neck muscle strength and neck pain is individual, which means that any rehabilitation program should be tailored to each individual.

Whether maximum muscular contractions were truly "maximum" may be questioned, at least if some of our symptomatic pilots had neck muscle pain. However, it cannot be excluded that RG pilots carried out the training by using their neck muscles more appropriately, i.e., in a way tailored for pilots. This might, to some extent, explain why they improved when performing the measurements. Whether this helps when flying, however, remains to be studied.

We conclude that the continuous contact between the physiotherapist and the pilots throughout the entire study, with repeated reinforcement of the neck muscle training program, encouraged the pilots to carry out the exercises, which led to increased neck muscle strength and endurance. In order to find out whether a reduction of complaints is possible, the frequency of complaints may need to be followed in a larger group of pilots over a longer period with, possibly, more intensive and more specific training. However, the correlation between neck muscle strength and endurance, respectively, and neck complaints might be individual, meaning that any rehabilitation program for neck complaints should be tailored for each individual.

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REFERENCES

1. Alricsson M, Harms-Ringdahl K, Linder J, et al. Mobility, muscular strength, and endurance in the cervical spine in Swedish Air Force Pilots. *Aviat Space Environ Med* 2001; 72:336–42.
2. Drew WED. Spinal symptoms in aviators and their relationship to G-exposure and aircraft seating angle. *Aviat Space Environ Med* 2000; 71:22–30.
3. Harms-Ringdahl K, Ekholm J, Schüldt K, et al. Load moments and myoelectric activity when the cervical spine is held in full flexion and extension. *Ergonomics* 1986; 29:1539–52.
4. Harms-Ringdahl K, Schüldt K. Maximum neck extension strength and relative neck muscular load in different cervical spine positions. *Clin Biomech* 1988; 4:17–24.
5. Harms-Ringdahl K, Ekholm J, Schüldt K, Linder J. Neck problems in the Air Force: Cervical spine sagittal load and muscular strength. *Biomech Sem* 1991; 5:9–21.
6. Highland TR, Dreisinger TE, Vie LL, Russell GS. Changes in isometric strength and range of motion of the isolated cervical spine after eight weeks of clinical rehabilitation. *Spine* 1992; 17(Suppl.6):77–82.
7. Hämäläinen O. Fighter pilot's neck pain [doctoral thesis]. Kauhava, Finland: The Air Force Academy, Department of Physical Medicine and Rehabilitation, Oulu University; 1993.
8. Hämäläinen O. Flight helmet weight, + G_z forces, and neck muscle strain. *Aviat Space Environ Med* 1993; 64:55–7.
9. Hämäläinen O, Vanharanta H, Kuusela T. Degeneration of cervical intervertebral disks in fighter pilots frequently exposed to high + G_z forces. *Aviat Space Environ Med* 1993; 64:692–6.
10. Hämäläinen O, Vanharanta H, Huipli M, et al. Spinal shrinkage due to + G_z forces. *Aviat Space Environ Med* 1996; 67:659–61.
11. Hämäläinen O, Vanharanta H, Heinijoki H. Neck training and +G_z-related neck pain: A preliminary study. *Mil Med* 1998; 163:707–8.
12. Hämäläinen O, Toivakka-Hämäläinen SK, Kuronen P. +G_z associated stenosis of the cervical spinal canal in fighter pilots. *Aviat Space Environ Med* 1999; 70:330–4.
13. Jordan A, Mehlsen J, Östergaard K. A comparison of physical characteristics between patients seeking treatment for neck pain and age-matched healthy people. *J Manipulative Physiol Ther* 1997; 20:468–75.
14. Kikukawa A, Tachibana S, Yagura S. G-related musculoskeletal spine symptoms in Japan Air Self Defense Force F-15 pilots. *Aviat Space Environ Med* 1994; 65:269–72.
15. Knudson R, McMillan D, Doucette D, Seidel M. A comparative study of G-induced neck injury in pilots of the F/A-18, A-7, and A-4. *Aviat Space Environ Med* 1988; 59:758–60.
16. Levoska S, Keinänen-Kiukaanniemi S. Active or passive physiotherapy for occupational cervicobrachial disorders? A comparison of two treatment methods with a 1-year follow-up. *Arch Phys Med Rehabil* 1993; 74:425–30.
17. Mason KT, Harper JP, Shannon SG. Herniated nucleus pulposus: Rates and outcomes among U.S. Army aviators. *Aviat Space Environ Med* 1996; 67:338–40.
18. Newman DG. Cervical intervertebral disc protrusion in an RAAF F-111C pilot: A case report. *Aviat Space Environ Med* 1996; 67:351–3.
19. Newman DG. + G_z-induced neck injuries in Royal Australian Air Force fighter pilots. *Aviat Space Environ Med* 1997; 68:520–4.
20. Newman DG. Head positioning for high + G_z loads: An analysis of the techniques used by F/A-18 pilots. *Aviat Space Environ Med* 1997; 68:732–5.
21. Oksa J, Hämäläinen O, Rissanen S, et al. Muscle strain during aerial combat maneuvering exercise. *Aviat Space Environ Med* 1996; 67:1138–43.
22. Petré-Mallmin M, Linder J. MRI cervical spine findings in asymptomatic fighter pilots. *Aviat Space Environ Med* 1999; 70:1183–8.
23. Schall DG. Non-ejection cervical spine injuries due to + G_z in high performance aircraft. *Aviat Space Environ Med* 1989; 60:445–56.
24. Yacavone DW, Bason R. Cervical injuries during high G maneuvers: A review of Naval Safety Center data, 1980–1990. *Aviat Space Environ Med* 1992; 63:602–5.
25. Ylinen J, Ruuska J. Clinical use of neck isometric strength measurement in rehabilitation. *Arch Phys Med Rehabil* 1994; 75:465–9.

Physiologic Challenges to Pilots of Modern High Performance Aircraft

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Additional information is available at the end of the chapter

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Abstract

Fourth generation aircraft, such as the McDonnell Douglas F-15 “Eagle,” and the fifth generation platforms that followed, including the Lockheed Martin F-22 “Raptor,” pose unique physiological challenges to arguably the most important “system” on the aircraft, the human. Advances in aeronautical engineering have enabled next-generation aircraft to operate well beyond the natural limits of human endurance. Although the demand for unmanned systems is increasing exponentially, continued use of manned aircraft is still desirable within civilian and military operations for various safety and security reasons. With the continued presence of pilots in cockpits, future aircraft designers will require a basic understanding of the unique physiological factors affecting human performance in this domain. Given knowledge of human limitations, strategies for real-time on board monitoring of the “human system” may be employed to increase the safety of the pilot and aircraft.

Keywords: fifth generation aircraft, aerospace medicine, acceleration atelectasis, future of manned flight, human cockpit monitoring

1. Introduction

Aerospace Medicine is a sub-specialty within the broader Occupational Medicine discipline, requiring licensed physicians to complete specialized training to ensure and enhance the health, safety, and performance of individuals exposed to air and space operational settings. Unique hazards in these environments include exposure to microgravity conditions, various radiation sources, multi-axial G-forces, and hypoxic conditions, among others. Aerospace medicine practitioners often further specialize in niche aspects of aerospace medicine, applying

human performance enhancement (HPE) and human systems integration (HSI) tenets to both hyperbaric environments (dive medicine) and hypobaric disciplines (space medicine, high-altitude wilderness medicine). Additionally, some specialize in human dynamics; focusing on highly integrated “man-machine” challenges such as high-performance aircraft and ejection seat emergency escape technologies [1]. As human factors specialists, Aerospace Medicine specialists are ideally suited to participate in the development of new life-support systems in modern aircraft. Unfortunately in recent times, there appears to be a decrease in the medical role during initial design and testing, leaving medical specialists scrambling to make sense of new physiologic ailments after an aircraft has become operational. This has not always been the case. This chapter will address emerging challenges to human health in modern “next generation” fighters as well as ways in which engineers and aerospace medicine professionals may address them.

1.1. Brief history of aerospace medicine

Scientific interest in the effects of human and animal exposure to high-altitude environments can be traced to the observations of Father Jose de Acosta in the late 1590s, more than 300 years before the Wright brothers first flew their *Flyer* among the dunes at Kitty Hawk, North Carolina. Evaluating the Andes high-altitude mountainous environment, Father Acosta surmised the thin “element of air” was causing animals and humans to become ill [2]. Decades later, in 1643, Evangelista Torricelli created the first experimental vacuum. In honor of his accomplishments physical units of pressure were named after him and are known as torrs [3]. Later, Robert Boyle of “Boyle’s Law” fame, described the first case of decompression sickness when he observed bubble formation in the eyes of a viper exposed to vacuum environments [4].

Research on the physiologic responses specific to flight took place among early balloonists. On September 19, 1783, brothers Joseph and Etienne Montgolfier sent aloft a duck, a rooster, and a sheep to elucidate hypoxia-like effects on mammals [5]. Unfortunately, shortly thereafter in 1783, researcher Jacques Charles, of Charles’ Law fame, endured the first aviation mishap. While piloting a balloon, his passenger unexpectedly exited the basket, thus lightening the balloon and triggering a rapid ascent to an approximate altitude of 10,000’ MSL, causing Charles to experience ear and sinus pain [6]. Even one of the United States’ founding fathers, Benjamin Franklin, took an early interest in high altitude research when he asked early balloonist Dr. John Jeffries to take his pulse during a flight. Jeffries noted that his pulse increased from 84 beats per minute (bpm) at sea level, to 92 bpm at an altitude of 5812’ MSL [7].

Regrettably, the first fatalities in aviation occurred on June 15, 1785 when Pierre de Rozier and Pierre Romain unsuccessfully attempted to pilot a balloon across the English Channel. Thirty minutes after takeoff their balloon caught fire, killing both of them. Interestingly, this event also witnessed the first ground casualty, although not as a direct result of impact; De Rozier’s fiancée, who witnessed the event, subsequently collapsed and died. Other notable medical incidents occurred during early balloon flights including the first in-flight emergency (IFE) when, on March 7, 1809, John Pierre Blanchard experienced a cardiac arrest, otherwise known as a “heart attack,” while piloting his balloon. During the episode, he fell from his balloon from a height of approximately 50’, dying a year later from his related injuries [7].

One of the early grandfathers of Aviation Medicine was French physiologist Paul Bert. He trained in engineering, law, physiology, and medicine. His work included experiments demonstrating oxygen toxicity on animals as well as the therapeutic nature of oxygen in relieving symptoms found in balloonists at altitude. In 1878 he wrote *La Pression Barometrique, Recherches de Physiologie Experimentale*, which was so comprehensive it was later translated into English and used by early aerospace physicians during World War II [4, 8].

The Wright Brothers, with their successful flight on December 17, 1903, ushered in the age of powered heavier-than-air flight. Within 5 years, on September 17, 1908, the first passenger died in an aircraft accident. Orville Wright was demonstrating the latest model of the Wright Flyer to the US Army when the right propeller broke in flight leading to a stall and crash. The passenger on that flight was Army Lieutenant Thomas Selfridge who suffered a skull fracture. Despite attempts at early neurosurgery, Lt Selfridge died 3 h later. Orville himself suffered four broken ribs, a broken thigh, and a dislocated hip. It was felt that Lt Selfridge may have survived had he been wearing head protection and as a direct result of this accident, one of the first human safety measures in aviation was employed: the use of a helmet [9]. Later, after all six of the Wright model C aircraft, which the army had purchased, crashed, further engineering safety measures were taken by the US Army. An investigation board felt that “pusher” type aircraft were more unstable and a crash would result in the engine, which was situated behind the pilot, coming forward and crushing the aviator. Subsequent US military aircraft of the era had engines in the “tractor” configuration [10].

Aside from aircraft design, advances in pilot selection began to make aviation safer. Pre-war aviators often were those found to be unfit for the infantry. Even early in World War 1 “soldiers disqualified for further combat because of battle fatigue, shell shock ... became pilots.” The end result was up to 42% of aircraft losses and deaths may be caused by “human factors” [11].

In this setting Dr. Theodore Lyster appeared. Dr. Lyster is considered by many to be the “Father of Aviation Medicine.” An American Army doctor, he arrived in Europe in December of 1917 and spent 3 months studying pilots and conditions affecting their performance. He then returned to the United States and established the Air Service Medical Research Lab on Long Island which had a hypobaric chamber. He developed new medical standards for the US Army Air Corps. In addition it was Dr. Lyster who first introduced the term “flight surgeons” when describing physicians who specialize in caring for aviators, and he was instrumental in ensuring that flight surgeons were part of each flying unit and would deploy with their squadrons rather than being assigned to a separate larger medical command [12]. This practice is still in place today in the United States military where an assigned flight surgeon is an integral part of each squadron.

Despite these new standards set by Dr. Lyster, it seemed as if the medical and aviation communities were in a perpetual battle between standards that were too rigid and aviators who excelled despite physical defects which would have otherwise grounded them. One famous civilian who personified this was Wiley Post who lost his eye in an oil rig accident early in his aviation career. He subsequently went on to become the first pilot to solo around the world, discover the jet stream, and he created the first practical pressurized suit for high altitude flying [13].

Additional examples of highly skilled pilots who did not meet the current medical standards are found in World War 1. One of the most famous American units to fight in the war was the Lafayette Escadrille. These flyers, several of whom obtained the unofficial title of “Ace” after downing five enemy aircraft, were hard worn by their combat service. Many of the members could not meet the Army Air Corps medical standards. Raul Lufbery, the triple Ace, was “over-age, had rheumatism, and could not walk a straight line backwards.” Others had poor vision, color blindness, and injured extremities. Eventually these pilots would be granted special approval so their valuable experience would not be lost in a fledgling service so in need of experienced veterans [14].

The controversy continued into World War 2, where one can find any number of stories of aviators “cheating” at their eye exam. This includes Robert Morgan who would later pilot the “Memphis Belle,” one of the first B-17s to famously complete all its required missions with its crew intact [15]. After the war Chuck Yeager broke the sound barrier with broken ribs after he fell from his horse, a condition which would have surely temporarily grounded him had he disclosed it to his flight surgeon [16].

In recent years, there has been a shift in the medical community from a restrictive approach, to the perspective of “how do we keep aircrew in the cockpit.” An example of this is seen in how NASA decided to return to space the well-known astronaut Story Musgrave after he underwent cataract surgery [17]. A further example is the United States Air Force’s lifting of restrictions on pilots who have had laser corrective eye surgery, or the fact that the Federal Aviation Administration (FAA) grants Special Issuances which by 2014 constituted 6% [18] of all certificates. It is with this mindset that the rest of the chapter is devoted, that of keeping the pilot in the cockpit even when technological advances push the limits of human endurance.

1.2. Current training and educational programs of aerospace medical personal

In the United States there is a wide array of education and training among the physicians who work in the realm of aerospace medicine. There are two primary tracks, military and civilian, with each track consisting of a “basic” and “advanced” level. The advanced levels of each track graduate medical specialists competent to become board certified in Aerospace Medicine under the purview of the American Board of Preventive Medicine.

In the military, physicians are referred to as flight surgeons. “Basic” flight surgeons attend their service’s specific primary courses, after which they are considered flight rated officers in the U.S. Military. Military flight surgeons have graduated medical school and have completed 1 year of post-graduate training, typically referred to as an intern year. Each branch of the military has different course requirements and duration to obtain “basic” flight surgeon status. The Air Force program consists of three courses of several weeks’ duration which include classroom training as well as civilian and military flight experiences. Students are exposed to hypobaric conditions using altitude chambers and those who fly with fighter aircraft are tested in centrifuges. Basic Army flight surgeon training is similar with an emphasis placed on rotary wing aircraft and Blackhawk helicopter simulations. The Navy program is substantially longer

and includes phases in which Naval flight surgeon candidates take basic ground school side by side with student Naval and Marine aviators, as well as significantly more “stick time” in both rotary and fixed wing aircraft. Regardless of the branch, all military flight surgeons are expected to fly with their assigned aircraft. In this way trust is built between the flight surgeon and his/her aviator patients, and the rigors of flight can be experienced firsthand, something which cannot be gained from medical books or classroom didactics (**Figure 1**). Physicians in the civilian sector who certify civilian pilots under Federal Aviation Administration (FAA) guidelines are referred to as Aviation Medical Examiners (AMEs). These are physicians trained and designated by the FAA to certify pilots’ medical certificates. Physicians can be trained in any specialty with the requirement that they attend a 1-week course with refresher training every 36 months [19].

Advanced training in Aerospace Medicine leading to board certification is significantly longer than civilian or military basic courses and lasts 2–3 years depending on the program. These programs include the Air Force program located at Wright-Patterson Air Force Base, the Army program at Ft. Rucker in Alabama, and the Navy program located at Pensacola, FL. The civilian programs are located at the University of Texas-Medical Branch in Galveston, TX, and the Mayo Clinic in Rochester, MN [20]. All programs require completion of an MD or DO degree and at least 1 year (internship) in clinical care. In addition, most programs require students to obtain a Masters in Public Health during their time spent in training. Although there is naturally some overlap in topics covered, the programs then diverge in their education to focus on the specific needs of the respective military or civilian populations.

Military training focuses on a typically younger, healthier population that works with high-performing aircraft in challenging training and combat situations. Therefore a variety of training is needed including learning the flight environment, broad clinical experience, and even accident investigation. In addition, aerospace trained physicians in the military will also



Figure 1. United States military flight surgeons are mandated to experience the rigors of flight to better understand the physiologic demands placed on their aircrew patients. The rise of single-seat only aircraft are challenging the abilities of these medical professionals to diagnose and treat new ailments seen in modern fighter-type aircraft.

take care of family members of the aircrew, which expands the requisite medical knowledge needed for competent care.

The civilian programs focus on care for the civilian aerospace communities (commercial and private pilots, Air Traffic Control, etc.) and, more rarely, space crew and passengers. As mentioned previously, there has been a shift in medical evaluations from a restrictive approach to developing standards for safe return to flight after adequate medical evaluation and treatment. Therefore, there is a strong emphasis on clinical experience and working closely with the Civil Aerospace Medical Institute (CAMI) division of the FAA. In the case of space crew members or passengers, training is coordinated with NASA, private agencies, and the FAA.

With increasing numbers of single-seat aircraft it is becoming harder for flight surgeons to actively participate in this unique environment (**Figure 2**). Fifth generations aircraft such as the F-35 and F-22 are all strictly single seat aircraft. When these modern aircraft have been associated with unusual and unexpected health concerns for their pilots, it has been more challenging for flight surgeons to diagnose and treat these problems since they cannot experience these conditions for themselves. A small cadre of military pilot-physicians exists, and they have been useful in human-machine risk assessment and mitigation approaches, but most flight surgeons serving high performance aircraft operations are limited in their ability to directly observe flight operations, and this has hampered investigations.



Figure 2. Advanced training in Aerospace Medicine may include further hands on exposure in high performance aircraft. Here, a United States Air Force Resident in Aerospace Medicine undergoes training in the T-6 Texan II aircraft with an instructor pilot during Medical Officer Flight Familiarization Training.

2. Decompression sickness in extreme high altitude aviation

2.1. Current cabin pressure control and mitigation strategies

Due to the altitudes flown by many high performance aircraft, cabin pressurization is important for a number of reasons. These reasons include hypoxia, hyperventilation, extreme temperature changes, as well as expanding trapped gasses and the risk for decompression sickness. Thus the need for protecting the pilot from stressors in the hypobaric environment is imperative.

Two physiologic responses to high altitude, hypoxia and hyperventilation, share similar symptoms and can be confused for one another. This confusion can make it difficult for aerospace medicine professionals as well as aircraft designers to determine the underlying cause of a pilot's symptoms. These symptoms include muscle cramps, paleness, and cold clammy skin. There may also be changes in mental status which can make a pilot's recall of the event difficult.

The interactions between hypoxia and hyperventilation are as follows, with the caveat that hyperventilation can also be brought about by other causes such as heat, air sickness, positive pressure breathing, and psychological stressors such as fear and anxiety. In brief, lower pressures lead to lower partial pressures of oxygen and increase the risk for hypoxia. Hypoxia in turn will increase respiratory rate, thus causing hyperventilation. With the increased respiration rate, blood CO₂ levels fall which in turn change pH. Changes in blood pH and CO₂ levels may lead to many of the symptoms and can negatively impact cerebral blood flow and thus a pilot's ability to process information and make decisions or react to emergencies.

Different strategies are employed to maintain cabin altitude in order to decrease the risks of high altitude and maintain pressures which are more tolerable for humans. These include isobaric, constant differential, and a sealed capsule. Modern airliners utilize an isobaric mode of pressurization, typically after reaching 6000–8000 ft. Any further increase in altitude beyond the predetermined altitude will not result in a corresponding change in cabin pressure. High performance aircraft on the other hand generally employ a constant differential strategy that maintains a constant pressure difference between the atmosphere inside and outside of the cabin. One advantage for military use with the latter system is, by allowing a higher cabin altitude, less catastrophic results may occur from damage incurred during battle, such as a damaged canopy which would lead to a major pressure breach.

Cabin pressure has typically been maintained by diverting high pressure “bleed air” from the aircrafts engines, cooling the air, then instilling it into the cabin. Since air is continually entering the cabin, it also needs to be released via a pressure valve. Thus aircraft cabins are not air tight and a continual supply of fresh air should always be entering the cabin. Unfortunately, flaws in the bleed air system have proven to be fatal. In 2010 an F-22 crashed in Alaska after an overheating engine caused the bleed air environmental control system and the onboard oxygen generating system to shut down [21]. The widow of the pilot filed suit against the major manufactures of the aircraft and eventually settled litigation. Interestingly the

lawsuit stated that the system was built “without adequate backup safety measures or proper sensors to warn the pilot if there is a problems” [22]. Of note, the Boeing 787 was designed to maintain cabin pressurization using electrical pumps versus bleed air systems. Whether this approach will be introduced in high performance aircraft remains a question.

2.2. U2 and other airframe exposures

Exposure to high attitude carries with it a significant risk of decompression sickness (DCS). DCS is thought to occur when inert gasses, primarily nitrogen, come out of solution within tissues at low barometric pressure. In aviation, the first reported cases occurred in high altitude balloons in the 1930s. The risk for DCS can be reduced for altitudes of 18,000–43,000 ft by breathing 100% oxygen prior to ascent for short exposure times of 10–30 min. This has the advantage of “washing out” excess nitrogen. Staying on 100% oxygen is required in flight if exposure to these altitudes is continued. Risk factors for DCS include physical activity at altitude, repeated exposures to altitudes greater than 18,000 ft, prior history of DCS, faster rates of ascent, alcohol consumption prior to ascent, persons with higher body fat, and scuba diving prior to flight. There is also some thought that increased age as well as prior long bone injuries put one at risk [23].

DCS is broken down to Type 1 or Type 2. Type 1 is less serious and involves musculoskeletal and skin illness, classically referred to as the “bends” and “creeps” respectively. Type 2 is more serious and involves neurologic and cardiopulmonary disease, the latter which is termed the “chokes.” Neurologic symptoms range from dizziness, ringing in the ears, numbness, bladder incontinence, and inability to walk, to seizures, coma, and death [24]. According to research conducted by the Air Force Research Laboratory (AFRL), descent from high altitudes to ground level is an effective treatment for altitude DCS. The majority (95%) of DCS sufferers who were tested at the AFRL were treated with ground level oxygen and saw a rapid decrease in DCS symptoms, while the remaining individuals were given hyperbaric treatment. Descent is an effective treatment method because DCS is caught early through crew monitoring in the controlled environment at the AFRL. During actual operations, it is likely that a higher percent of DCS sufferers would need hyperbaric treatment [25].

It was well known for years within the Flight Surgeon community that some pilots of high altitude aircraft were experiencing signs and symptoms consistent with decompression sickness and these were often underreported. This was particularly true in the Lockheed U2 community. In the past decade, pilot and researchers have been more open and a number of studies have been performed on U2 pilots as well as personnel who work as safety monitors inside altitude chambers. Excellent work by McGuire and colleagues has now been published in a number of studies. These studies report brain changes with repeated exposures to hypobaric normoxia. Specifically U2 pilots and altitude chamber staff have white matter changes which are seen on MRI [26, 27]. These changes have been linked to diffuse axonal injury [28] and those with a higher burden of white matter changes score lower on neurocognitive tests when compared to other pilots [29]. All these changes were linked to hypobaria without hypoxia, thus it seems low pressure itself may be a risk for permanent changes in the brain which can lead to subtle cognitive decline.

Future aircraft may go higher and even skirt the edges of space. Thus careful consideration needs to be given for aircrew protection. U2 pilots are equipped with a pressure suit, however as seen above, neurocognitive changes may already be occurring. One possible explanation may be that most pressure suits do not provide the wearer with a full 1 ATM of pressure, due to the need for a flexible suit, thus the pilot is exposed to hypobaria.

As opposed to chronic repeated exposures to hypobaria, acute exposure to high altitude, such as a rapid decompression, has its own set of problems. During acute exposure aircrew have a limited amount of time to institute measures to save themselves. This is termed “Time of useful consciousness” or TUC for short. Intuitively the higher an aircraft is, the less time is available for a pilot to save himself. By 50,000 ft an aviator only has between 9 and 12 s before they become unconscious (**Table 1**) [30]. Factors such as exercise and smoking will even further decrease that amount of time.

At the altitude of Armstrong’s Line, 63,000 ft, pressure is so low that water boils at body temperature (37°C), although due to the strength of skin in practice this typically does not occur at that level. Above that level the process of ebullism may occur, gas bubbles forming within bodily fluids. There have been accidents which have occurred at these altitudes, although not within fighter aircraft. Most recently the crew of the Space Shuttle Columbia died from this phenomenon. Although they were wearing pressure suits, none were able to close and lock their visors prior to incapacitation and some had their gloves off, thus limiting the protection received by the rest of the suit. Surprisingly exposure to these altitudes is survivable if caught and treated quickly enough. In 1966 a spacesuit technician working in a ground based chamber was accidentally exposed to the equivalent of 120,000 ft. He is reported to have felt the saliva “boiling” off his tongue as he passed out. He regained consciousness at 14,000 ft as he was repressurized. Amazingly he suffered no neurologic sequelae and did not even require hospitalization. In 1982 another ground based chamber accident exposed an individual to 73,000 ft for what is believed to be 1–3 min. After a 5-h hyperbaric recompression, he survived. More amazingly a 1-year follow-up revealed no neurologic abnormalities [31].

Altitude	Time of useful consciousness
18,000	20–30 min
22,000	10 min
25,000	3–5 min
28,000	2.5–3 min
30,000	1–2 min
35,000	0.5–1 min
40,000	15–20 s
43,000	9–12 s
50,000	9–12 s

Table 1. Time of useful consciousness “TUC” is the amount of time aircrew members have to institute life saving measures before they are incapacitated after acute exposure to the hypobaric conditions of high altitude.

Current fighter aircraft have been reported in the lay press to operate at extreme high altitude, although likely below the level of the Von Karmann line, which is at 47 miles and is the level at which the atmosphere is too thin for aerodynamic surfaces to control the direction of the aircraft. As fighter aircraft go higher and higher, the very real possibility of aircraft operations in the early reaches of space exist. With this in mind, systems which automatically detect cabin or “space suit” pressures may be needed. In the event of a pressure breach, either through accident or combat, there is mere seconds for a pilot to react. The life of the pilot and the aircraft itself may be saved by an “automated” copilot within the aircraft. This would necessitate a computer system taking over should there be a breach in the pressure system and the pilot not responding to an automated computer generated inquiry.

3. Acceleration, G-forces, and countermeasures

3.1. Brief explanation of G_x , G_y , G_z

During flight, acceleration and changes in vectors can cause changes in the amount of gravitational force that is experienced by a pilot. These can be positive (increased force) or negative (decreased force). Pilots feel forces acting on their bodies is in the opposite direction of the actual force vectors. This can be somewhat confusing so convention sets the positive directions of the acceleration forces. Unfortunately, multiple conventions are used which can further add to the confusion [32]. No one convention is better than another. One commonly used convention is the “right hand rule” (**Figure 3**). The pilot holds his right hand and fingers as indicated in the figure and the fingers then point in the positive direction of each force, $+G_x$ in the direction of the pointing finger, $+G_z$ in the direction of the thumb, and $+G_y$ in the direction of the middle finger.

Another way to think about acceleration forces is to think about how the eyes would move in response to the given acceleration [32]. When the pilot is experiencing $+G_x$ it is referred to as “eyeballs in,” and $-G_x$ is referred to as “eyeballs out.” One of the advantages of this convention is that it leaves little room for error since the experience of the pilot is exactly what is described.

3.2. Human limitations

There are limits to how much acceleration force the human body can tolerate. Tolerance depends on several factors including the magnitude of the acceleration force applied, direction, and duration as well as subject factors including age, weight, height, and blood pressure [33, 34]. Tolerance is somewhat subject to training, and there is wide variability between individuals. In addition, other factors can affect tolerance of G-forces including medical conditions, medications, and use of other substances (such as alcohol).

Despite the high number of variables that contribute to tolerance, one of the most important factors remains the direction of the acceleration force. Each axis has its own specific limitations in the positive and negative directions. For example, humans can tolerate $>10\text{ G}$ in the $+G_x$ direction while only about $2\text{--}3\text{ G}$ in the $-G_z$ direction. This is due to the fact that there are

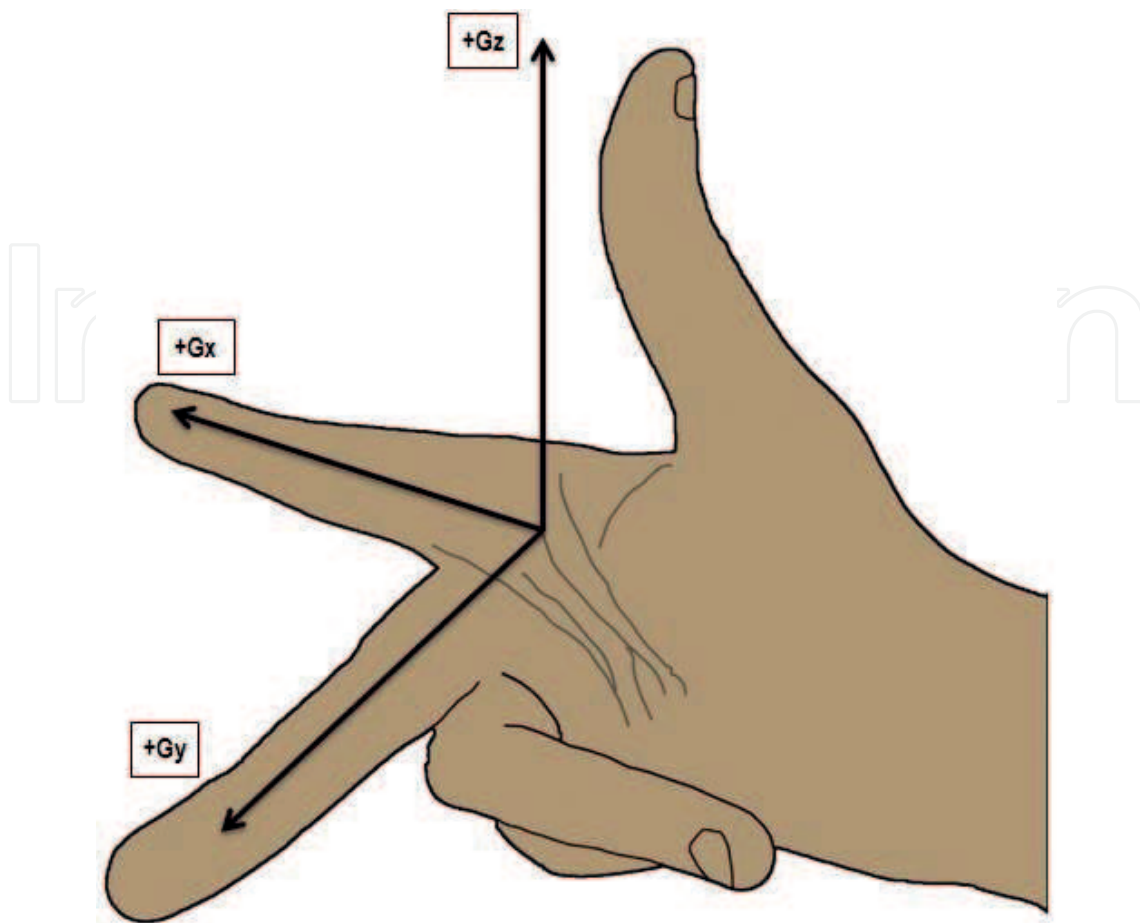


Figure 3. The right-hand rule. This figure demonstrates the “right hand rule” convention of G-force direction. The pilot holds his right hand and fingers as indicated in the figure and the fingers then point in the positive direction of each force, $+G_x$ in the direction of the pointing finger, $+G_z$ in the direction of the thumb, and $+G_y$ in the direction of the middle finger. As an example, when a pilot experiences $+G_x$ (which is pushing forward) the sensation felt is that of being pushed into the seatback (drawing acknowledgement Iaswarya Ganapathira, D.O.).

physiologic compensatory mechanisms to increase blood flow to the brain but none to prevent excess blood flow.

There are also different terms used to describe various aspects of G-force intolerance. “Gray-out” describes when vision loses hue and vision appears to be more gray. Tunnel vision describes the progressive loss of peripheral vision. “Blackout” is the complete loss of vision while still maintaining consciousness. “A-LOC” stands for “Almost Loss of Consciousness” and “G-LOC” describes a G-force induced loss of consciousness. “Red-out” describes the reddening of vision from negative G-forces which drive the lower eyelid into the field of vision.

3.3. Current countermeasures

Excessive G-forces may result in a sufficient reduction in blood flow to the brain such that G-LOC ensues. G-LOC can be and have been catastrophic and countermeasures have been developed to try and prevent G-LOC.

Physiologic countermeasures include physical training to improve overall fitness, cardiovascular function, positive pressure breathing for protection against G, and the anti-G straining maneuver [35]. These measures employ physical techniques to improve G tolerance. They can be helpful but have limitations as well.

Mechanical countermeasures revolve around the anti-G suit, positive pressure breathing (PPB), and (theoretically) cockpit design. During World War 2, Dr. Earl Wood was working as part of a laboratory team located at the Mayo Clinic charged with finding ways to improve G-force tolerance of pilots (**Figure 4**). Their work led to the development of the anti-G suit. The conventional “suit” is worn like trousers and, with the aid of a weighted valve, inflates when G force is above 2G. This compresses the lower extremities and abdomen using air bladders promoting return of blood back to the heart and head (**Figure 5**). Newer versions of the anti-G suit add higher G-force protection [36]. PPB works by assisting pilots to maintain oxygenation when G forces and constricting chest garments work to restrict chest movement and lung expansion. Wood et al. recommended changes in cockpit design to maximize G tolerance, recommending prone position as the best solution. An attempt to improve G tolerance by canting the seat backward was done in the F-16, and while appearing logical, was not supported by centrifuge testing. All recent high performance jets now place the pilot upright in the cockpit [37].

As more advanced aircraft have been created which test the boundaries of human tolerance, there has been ongoing interest in developing more advanced anti-G systems. One of these is the Advanced Technology Anti-G Suit which confers effortless protection up to +9 Gz and consistent protection up to +12 Gz with additional straining [38].

A new challenge for pilots in fifth generation aircraft is multi-axis acceleration wherein thrust vectors may be variable allowing increased aircraft maneuverability. G forces in these aircraft are likely to be multi-axis versus simple Gz or Gx forces. Effects on pilots remain investigational, with research ongoing in specially constructed centrifuge facilities [39].

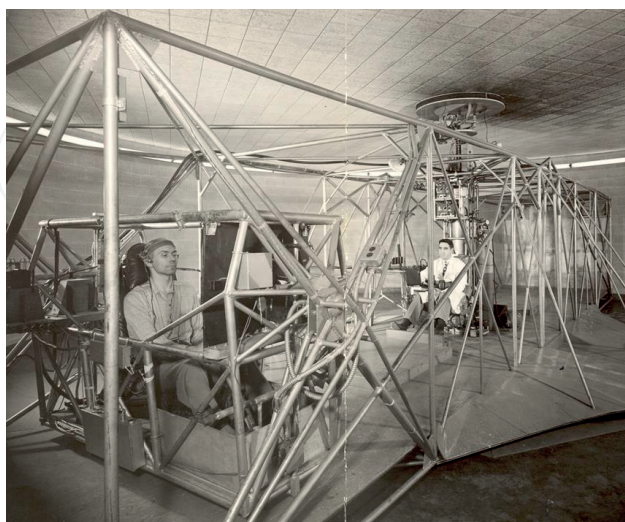


Figure 4. Dr. Earl Wood (on the right, wearing a white lab coat) is working in the Mayo Clinic centrifuge laboratory to help develop the G-suit.



Figure 5. Dr. Earl Wood is standing next to a display case exhibiting the G-suit he helped develop.

4. Acceleration atelectasis

4.1. Alveolar collapse under acceleration and increased oxygenation concentrations

Acceleration atelectasis is an old condition which has become new again. In healthy lung tissue, the smallest unit in the lung is the alveoli. These tiny sac-like structures are delicate and as described by John West in west's lung zones, blood flow through each region of the lung is influenced by gravity. Typically at the end of expiration the pressure in the alveoli is within 2 mmHg of atmospheric pressure. Current thinking of the pathophysiology of acceleration atelectasis is, under conditions of high G forces and high increased fraction of inhaled oxygen, alveolar collapse occurs in the dependent regions of the lung. This collapse can cause chest pain, shortness of breath, and cough [40].

Tacker and colleagues found that atelectasis, alveolar collapse, can be exacerbated by three conditions: the use of 100% oxygen, +Gz, and even by the anti-G suit itself. In their study Tacker exposed 12 subjects to aerial combat maneuvers under a range of forces spanning from 4.5 to 9 G. They found that above 5 G up to 50% of the pulmonary airways were in some way distorted and even closed. This distortion of the alveoli led to a reduction of up to 20% of the vital capacity, the greatest volume of air which can be exhaled after taking the largest possible breath, in the research subjects. The G-suit itself may further exacerbate the problem by elevating the diaphragm, thus decreasing vital capacity through extrinsic compression of pulmonary space [40].

The use of high inspired oxygen percentages requires explanation. Prolonged high levels of oxygen have long been shown to be detrimental to ICU patients or those undergoing anesthesia, likely due to another condition known as absorption atelectasis. Absorption atelectasis reflects the fact that the human respiratory system is so efficient at absorbing oxygen that it can be taken up more rapidly across the alveolar-capillary membrane than what can be delivered to the alveoli during normal pressure respiration [40, 41]. When the United States Air Force

developed the On Board Oxygen Generation System (OBOGS), Haswell and colleagues found a significant reduction in vital capacity at inspired oxygen concentrations above 70%. Haswell noted “Given the unpleasant nature of the respiratory symptoms and the absence of knowledge about the effects of repeated development of acceleration atelectasis, limiting oxygen concentration ... seems worthy of consideration” [42].

This reduced vital capacity could be alleviated by a cough, deep breath, or anti-G straining maneuver. Both Tacker and Haswell found the reduction in vital capacity could be relieved by positive pressure breathing at 30 mmHg. It is worth noting that standard patient ventilator practices in modern intensive care units limit the use of inspiratory pressures to “plateau pressures” less than 30 mmHg [40, 42]. As discussed later in this chapter, there is a need for continued research into this “old” concept of acceleration atelectasis.

5. Musculoskeletal injury and impact of life support systems and aircrew flight equipment

5.1. Neck injuries

Neck pain has been reported in up to 97% of all pilots [43]. Unfortunately the incidence varies tremendously as does its association with the type of airframe. A systematic review and meta-analysis of 20 articles conducted by Shiri and colleagues found no difference in the prevalence of neck pain, cervical disc degeneration, low back pain, or lumbar disc degeneration when they compared fighter pilots to helicopter or transport/cargo pilots. In the subset of high-performance pilots, they did however find that those who were exposed to higher G-forces were at a higher risk of neck pain, as were those that spent time looking over their shoulder in the “check-six” position [44].

There is disagreement regarding whether different models of high performance aircraft cause more neck pain. Some reports indicate as little as 18.9% prevalence of neck pain in F-16 pilots [45], while Verde and colleagues found an incidence of 48.6% in a small group of 35 F-16 pilots. This group had a much higher incidence than Eurofighter Typhoon pilots who only had a reported incidence of 5.7% in age matched controls. Verde speculated that the increased neck pain was secondary to the semi-recumbent seat position of the F-16 [46].

In F-15s, Chumbley et al. found a unique subset of neck pain and speculated it was due to cockpit layout. Similar to work done by Shiri, Chumbley found differences which may be attributed to the “check six” position. As part of their work which involved treating neck pain, Chumbley checked cervical range of motion and found rightward going cervical rotation improved after traction sessions. They speculated that F-15 pilots preferentially turned to the left due to cockpit layout, as the throttle is on the left side and slightly behind the stick which is placed center. In terms of treatment, Chumbley found that neck pain was statistically alleviated, when compared to controls, after cervical traction was applied to pilots after flying. The amount of cervical traction applied was roughly 10% of the pilot’s body weight [47].

In their literature review Chumbley and colleagues list proposed etiologies of neck pain experienced by high performance “fighter” pilots. These include high +Gz, rotation of the neck under +Gz (check-six position), fatigue, frequency of endurance training and physical exercise, and prolonged flexed posturing. From an equipment point of view, increasing the weight on the helmet may also place a pilot at risk. This is seen with the addition of night vision goggles as well as with the use of the Joint Helmet Mounted Cueing System (JHMCS). Countermeasures for the neck pain which have included strengthening and stretching exercises, spinal manipulation, and physical therapy have demonstrated mixed results, with spinal manipulation showing some promise [47].

5.2. Ejection seat injuries

In the early part of aviation history, pilots who found themselves in damaged or malfunctioning airframes had no real options to avoid impending death. Later, use of parachutes became common (though in WW 1 some services opted not to provide parachutes as they were worried pilots might leave their aircraft too readily) The challenge these pilots faced was how to escape the cockpit safely, either climbing or falling out when the situation would allow. In the jet age, one of the greatest advances in aircraft safety has been the ejection seat. Ejection seats are powered by rockets to expel the occupant from the cabin and away from the failing aircraft. Since time is of the essence in these situations, the rocket-propelled seat will violently eject the occupant. One common ejection seat, the ACES II, will reach 9-12G during the process which is significantly lower than other seats which could reach more than 18G [48].

Ejections seats, which were designed to save lives, have indeed accomplished that task. One manufacturer, Martin-Baker, keeps a tally of the pilots who have survived because of their ejection seats. In early 2017, their count was over 7500 lives saved because of their ejection seats [49]. However the use of ejection seats comes with the risk for potential bodily harm. Although injury is much more desirable than the alternative, efforts are still needed to focus on the prevention of injury to the extent that is possible.

One study looked at USAF injuries related to the use of ejection seats from 1981 to 1995. It was noted that injuries typically occurred in the head, neck, cervical spine, thorax, thoracolumbar spine, ribs, pelvis, and the upper and lower extremities. Injury rates were noted to be between 2 and 25%. Moreover, fatality was noted to occur in 0–11% [50]. Injuries can range from minor back strain that resolves on its own to as severe as a leg broken in 5 places. Continued work is needed in this area to preserve life and minimize injury.

5.3. Back injuries due to G-forces

Neck pain, as detailed above, and associated injuries are very common in aviation. Although the neck is the most susceptible area of the spine, G force-related injuries can occur along any aspect of the spinal column. Even in the controlled environment of centrifuge training, it is possible to sustain injury to the spinal column. One study assessed 991 subjects who were undergoing high G training in the centrifuge and found that 2.3% of them suffered from an

acute spinal injury [51]. In at least one case, the G-force from centrifuge training (which reaches up to +9Gx) was enough to cause a fracture in the lower spine in an otherwise healthy 32-year-old Flight Surgeon [52].

The addition of the highly stressful flight combat environment and more powerful aircraft increases the risk of injury. When the Japanese Air Self Defense Force introduced the F-15 Eagle into their fleet, there was a significant increase in musculoskeletal injuries related to the spine with 90% of surveyed pilots reporting pain [53]. There is some ongoing debate in the literature regarding how important these types of injuries may be and what impact they might have on the long-term health of subjects. One systematic review, which included 20 individual studies evaluating spine injury in pilots, found no statistically significant difference in back pain between pilots and non-flying personnel [44]. One possible interpretation of these conflicting pieces of information would be that ejection seats are indeed getting safer, and we are seeing improvement in back injuries. We would hope to see similar improvements in other areas as well.

6. Environmental factors

6.1. Noise

Measured in decibels (dB), sound is an auditory sensation in response to acoustic stimuli. Subjectively, any undesired sound is considered noise. Since the advent of heavier-than-air flying machines, both sound and noise remain inherent elements of manned aircraft operations, and modern high performance aircraft operations are no exception. While the majority of unwanted sound is generated by the power plant, several other sources of operationally innate noises include vibrations and sounds secondary to weapons system deployment. Regardless of the source, sound and noise exposures that exceed permissible exposure limits, as published by the Occupational Safety and Health Administration and the National Institute for Occupational Safety and Health, have the potential to result in injury.

Effects of noise on overall health have been studied. Deleterious effects have been seen in hearing, ringing in the ears, cognitive performance, and possibly even hypertension [54–57]. Although engineering can potentially mitigate much of external noises, there remains a need to relay critical information to the aircrew in the form of voice communication. This will place limits on the amount of noise mitigation that can be engineered into the system.

It is also important to distinguish between sound and noise exposures that aircrew experience while operating within a closed cockpit/flight deck versus the external environment experienced when approaching their aircraft while other aircraft operations are ongoing. As an example, the F-35A Lightning II is a fifth-generation fighter which has a measured aircraft ground noise level of 145 dB when the throttle is set to “Military Power” and 149 dB when set to “Afterburner” [58]. Obviously, the relative attenuation of the closed cockpit environment serves as an effective adjunct to triple hearing protection utilizing traditional earplugs in conjunction with the physical protection of a helmet and the acoustic protection of active noise-canceling technology. However, with the threshold of pain occurring around 120–

140 dB [59], it is reasonable to conclude that sound and noise considerations will remain critical in aircraft design and deployment as long as humans intend to work in or around them.

6.2. Vibration

Another factor that aircrew deal with is the vibrational forces created by the powerful machines at their command. One study looked at the effect of vibration on the ability to perform complex tasks and found that certain vibration patterns reduced cognitive performance [60]. Another study found that excess vibration can cause temporary hearing loss and impaired vision [61]. Another group studied vibrational effects and found that it reduced motion control [62]. In addition, airborne vibrations were found to cause symptoms of nausea, coughing, headache, and fatigue [63]. One of the most reported effects is that of back pain. It appears to affect rotary-wing aircrew more than fixed-wing aircrew as the former experience much more vibrational forces than the latter. Long term these effects may lead to chronic problems [64, 65]. Any of these adverse health effects could jeopardize safety and warrant continued efforts at mitigation.

6.3. Thermal stress

Another potential physiologic stressor to pilots is thermal stress. Humans are most comfortable in ambient temperatures ranging between 15 and 30°C [66]. There is the potential for cockpit temperatures to rise significantly above this comfortable range. Reports from pilots in the 1960s state that on hot days sitting on the steaming runway, temperatures in the cockpit climbed to nearly 60°C [67]. Even in 2015, it is still possible for cockpit temperatures to exceed 45°C. Sweating can unfortunately exacerbate the problem by increasing cockpit humidity and creating a greenhouse effect. The latest cooling systems try to adjust for humidity as well [68]. Additionally, systems malfunction and a pilot can become stuck inside the cockpit with the canopy down as occurred in an F-22 in 2006. The F-22 canopy system failed and was unable to be fixed or opened manually. Over the next 5 h, crews worked to cut off the canopy from the aircraft, during which cockpit temperatures rose throughout the extraction [69].

Thermal stress has significant implications aside from simple discomfort. Pilots report increased fatigue levels and decreased G-force tolerance under high thermal stress [70]. This can negatively impact performance and pose significant risk. Although efforts have been made to minimize the impact of thermal stress and improvements have been made, there remains ongoing concern in this area.

6.4. Toxins/fumes

Since the early days of aviation, toxins have impacted the health of both the aviator and the ground crew. Perhaps the most well-known of these is the reports of castor oil's effects on WW1 pilots. Although difficult to verify, castor oil *may* have been the cause of significant diarrhea in combat pilots. It is believed to have been thrown off by the engine and subsequently inhaled or ingested by the pilot sitting directly behind the engine [71].

One WW1 era toxin which has been confirmed is tetrachloroethane. For the ground crew, and those building WW1 aircraft, tetrachloroethane was found to cause significant adverse health effects, including death. It was used ubiquitously by all major combatants during the conflict as the varnish, also known as “dope,” to cover the fabric of the plane’s wings. Unfortunately reports after the war linked this toxin to at least 70 illnesses and 12 deaths. Many of the symptoms appear to have been hepatic/liver failure with transmission of the toxin through both inhalation and transdermal routes [72–75].

Although not next generation fighter type aircraft, there has been work within the commercial airline sector on this topic. In modern commercial aircraft, multiple volatile liquids exist in the various systems of an aircraft. Because air is circulated around the engine to be heated and pressurized, it is possible for cabin air to become contaminated with various fumes. There have been multiple reports from aircrew and passengers alike complaining of this occurrence. Symptoms associated with contaminated air include fatigue, dizziness, and anxiety [76]. More concerning is the increased rates of cancers, cataracts, and motor neuron diseases that may be associated with exposures, although at doses higher than would be expected in cabin air contamination events [77]. Despite the numerous concerns, investigations into cabin air quality of civilian airliners have repeatedly shown that the air quality on commercial flights is very good and there is no consistent exposure that should affect the general public. As Bagshaw, referencing cabin air quality, concludes in his article, “Aviation medical professionals throughout the world continue to monitor the scientific evidence and remain receptive to objective peer-reviewed evidence” [78].

In military aircraft, hydrazine is a specific example of a toxin which is of medical concern. Present in some current 4th generation fighters, such as the General Dynamics F-16 “Fighting Falcon,” it is used to power the emergency power unit (EPU) and is added to other rocket and jet fuels. Routes of exposure include inhalation, ingestions, or even absorption through the skin and eyes. Animal studies have shown liver damage and the potential for cancer formation [79, 80]. Exposure in humans can cause skin burns, dizziness, lethargy, vomiting, contact dermatitis, and conjunctivitis. Long term exposure has been reported in one case to lead to pulmonary edema, intestinal hemorrhage, liver necrosis, and death [81]. Due to the continued need for this potentially deadly material, the United States Air Force has instituted a multidisciplinary approach to dealing with this hazard. From the medical side, a surveillance program looking at labs such as baseline liver function is conducted on those potentially exposed. Furthermore the workers themselves are educated in minimizing exposure, safe handling when necessary, as well as the correct response to an accidental spill [82].

6.5. Radiation exposure: both natural and manmade

Radiation exposure is an area of ongoing concern. Typically our atmosphere protects us from most harmful waves from our sun or other sources of such as cosmic radiation. While operating at high altitude, there is less atmosphere to protect the aircrew and the job of protection falls to the windshield and skin of the aircraft, which may not be as adequate as hoped. One study estimated that pilots who fly for 56 min at 30,000 ft are exposed to the same amount of UV-A radiation as someone sitting in a tanning bed for 20 min [83]. However, as in other areas

this is controversial. For example, one study found no measurable increase in UVA/UVB/UVC radiation in flights at cruising altitude. Interestingly, UVA levels inside the cabins were actually lower than on the ground based upon the collected data [84]. Pilots have been shown to be at increased risk of other cancers including brain cancer and Hodgkin's disease [85]. However again, there is controversy regarding if cosmic radiation is solely responsible for this increased risk of cancer [86]. Another complicating factor is that sometimes there appears to be an increased risk of developing a cancer with no associated increase in the risk of death [87]. This raises questions of how clinically significant an increase in risk might be, whether a risk even exists, and whether it is important to address or not.

Design of aircraft cannot fully eliminate the exposure to higher levels of cosmic radiation during flight. Flight practices have changed allowing pilots to retire at a later age, thereby allowing a higher lifetime exposure. As such, we must continue to monitor the impact this has on pilot health and find ways to mitigate any adverse effects.

7. Current issues and controversies

7.1. Hypoxic-like incidents in modern jet fighters

As described above acceleration atelectasis is a pulmonary condition which was well known and described in the literature by the generation of Aerospace physicians active during the 1950s and 1960s. This "corporate knowledge" seems to have faded. A literature review conducted in 2017 on this topic in a major data base revealed only 15 relevant articles. Of these one article was speculative, one was historical, three were review articles, thus leaving only 10 articles. Furthermore these articles began in 1963 and ended with the last basic research article written by Tacker in 1987. Not included in this search was excellent work performed by Dr. J. Ernsting which was published in the 1960s. His research recommended up to 40% nitrogen for cabin altitude levels of 25,000 ft [88].

This older research has been revisited due to respiratory complaints reported in new fifth and some older fourth generation fighters. Most notably pilots of the United States Air Force's F-22 Raptor, a fifth generation stealth fighter, began to experience "hypoxia-like" symptoms in 2008. Due to the rising number of incidents and the subsequent fatal crash of an F-22 in November 2010, the F-22 fleet was subsequently grounded twice in 2011 [89]. After considerable effort to investigate possible causes, the problem was thought to be fixed after researchers came to believe the cause was effects of the upper body pressure vests on pilots' G-suits and narrow oxygen hoses [90, 91]. While the F-22 fleet was returned to flying, unfortunately problems have continued with "hypoxia-like" symptoms now seen in other aircraft. This has led to the grounding of both the newer F-35 Joint Strike Fighter as well as the United States Navy's T-45 jet trainer, an older aircraft [92, 93]. Problems have also been cited with the U.S. Navy's F-18 Super Hornet and the RAF Tornado, both of which use the OBOGS to supply oxygen to pilots.

Although the root cause of these symptoms was initially felt by some, including the United States Air Force Scientific Advisory Board, to be due to hypoxia, some experts have suggested

an alternative explanation including acceleration atelectasis. Indeed some of the symptoms reported by pilots, (cough, shortness of breath, chest pain) are very reminiscent of acceleration atelectasis [94, 95]. Other possible explanations put forth by renowned pulmonary researcher John West include reduced cerebral blood flow due to high +Gz, hyperventilation, CO₂ retention from increased work of breathing, decompression sickness, or even toxic fumes [94]. Regardless of the cause, both West and the USAF Scientific Advisory Board (SAB) have called for in-flight monitoring and warning systems.

7.2. Studying cognition in hypoxia

Loss of cabin pressure can occur quickly in rapid depressurizations or, more insidiously and dangerously, with gradual or slow depressurizations. United States military aircrews are taught to learn their individual symptoms by experiencing them first hand in hypobaric “altitude” chambers. When aircrew experience these symptoms, they are trained to react by going on 100% oxygen (“gang load” their regulators) to ensure their oxygen equipment is working correctly and when in doubt, to transfer to stored oxygen (“pulling the green apple”), descend to less than 10,000 ft, and communicate with the ground by declaring an in-flight emergency.

Due to the number of decompression sickness (DCS) incidents seen during such training, many military and civilian groups are now transitioning away from hypobaric hypoxia training in the altitude chamber toward normobaric hypoxia training which uses mixed gas to allow aircrew to experience hypoxic symptoms. While initially safer (fewer DCS events), this approach may lead to the potential that the symptoms experienced by the pilot in training may be different if those symptoms are due to hyperventilation during low pressure as opposed to hypoxia.

Additionally the concept of time of useful consciousness “TUC” is a somewhat crude and individually variable measure to describe the neurocognitive function of an aircrew exposed to high altitude. Researchers at Mayo Clinic are currently working on ways to detect subtle degradation due to hypoxia using other physiologic parameters, such as eye tracking, transcranial Doppler, ECG R-R’ variability, EEG, etc. [96] (**Figure 6**). After laboratory data are analyzed, future work will be needed to incorporate these findings into an aircraft in order to best support and alert a pilot to the possibility of slow cognitive decline way before TUC becomes an issue.

7.3. Studying cognition in high workload

Pilot workload in flying high performance aircraft has increased largely due to accelerating informational flows. Cockpits, while seemingly simpler in appearance, present multiple and layered details on the flying environment, navigational elements, mission specific data, and systems integration awareness items. Military pilots often are in contact with multiple ground, space, and aviation related resources. Warning systems often overlap or produce simultaneous alarms. Net-centric warfare allows for vast quantities of information to be readily available at the finger-tips of modern airmen. There may be a time in the near future when this information

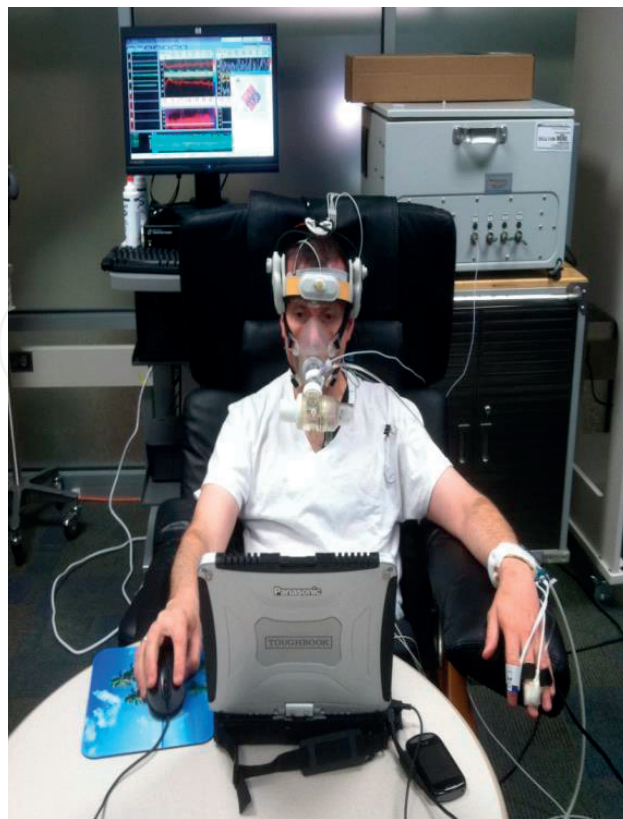


Figure 6. Ongoing experiments at Mayo Clinic evaluating the physiologic responses which may be early signs of cognitive degradation during exposure to normobaric hypoxia.

is employed in such a way that a pilot in a manned aircraft would control a “squadron” of unmanned/drone aircraft. The primary processing center for these information flows is the pilot’s brain. In this setting it would be very advantageous to know the mental state of the pilot in terms of cognitive overload. Thus if one pilot was showing signs of cognitive decline, from any source whether it is due to overload or a physiologic even such as hypoxia, control of unmanned resources could automatically be passed to another manned system, or mitigation algorithms could assist the pilot to reduce overload or stressors.

There are a number of physiologic measures which have been shown to reveal a subject’s current cognitive load. These may prove useful if studied to define envelopes wherein performance predictions may be calculated and applied. While incapacitation is critical to detect, it would be better to detect degradation in the early phases to avoid incapacitation. Many of the monitoring and mitigation approaches have limitations which need to be understood if employed.

Relatively recent advances in eye tracking have linked subjects’ cognitive loads to pupil diameter in a variety of tasks such as sports and driving [97, 98]. Not only has pupil diameter shown to be a useful measurement, but so too does the amount of eye movement and even blink rates [99]. Because the eye muscles are the most sensitive muscle to oxygen depletion, eye tracking may also be a good indicator of hypoxia [100]. Limitations of eye tracking may

include difficulty detecting pupils during G-forces that may pull eyelids down thus obscuring the pupils. Also, due to the continual movement of a pilot's head, eye tracking may be better performed by a device which moves with head motions. This would suggest a likely location for an eye tracker to be on/in a pilot's helmet [101–105].

Aside from eye tracking, heart rate variability has been demonstrated by some to also correlate with physiologic reserve and potential cognitive stress. Each peak on an EKG is called the “R” wave. By measuring the distance between successive “R” waves, it has been found that the R to R interval continually changes. In fact there is more variability in young healthy individuals than those who are older and sicker. The latter have a more “fixed” interval with less variation. This decrease in variability has also been seen during increased cognitive load [106]. Further work would need to see if this can be practically performed regularly in flight.

Cognitive function measuring devices have included measurements of ocular saccades (rapid eye movements which change the point of eye fixation from one point to the next), EEG monitors, pupil size, and even eye blink velocity [103]. Practical use of these devices has been limited in the cockpit due to the technical issues such as difficulty of applying electrodes in the first case, bulkiness and reliability of devices and difficulty positioning sensors due to space limitations or changes in signaling under acceleration forces. Much more study is needed in this field but it is clear that in-flight monitoring will be an element in future manned flight.

8. Conclusion and the future of manned flight

An in-flight monitoring and warning system may be one way to safely keep “pilots in the cockpit.” One theoretical concept would be to monitor various physiologic parameters of the pilot. If physiologic parameters were found to fall outside of normal reference ranges, one could conceive that an auto-pilot would be activated and either takeover flying the aircraft completely or “ask” the pilot if it could assist. This could occur until the pilot was able to regain control, or it may need to “safely” eject the pilot and self-land the aircraft.

This may seem to be very futuristic, but similar technologies already exist. Although not directly measuring the pilot's physiology, newer block F-16s have begun to incorporate an auto-ground collision avoidance system (Auto-GCAS) as of 2014. This system compares the predicted flight path against the known terrain and institutes an automatic recovery if the two are predicted to touch. In an aircraft known to have increased risk for G-LOC, especially in new pilots, this system has already been credited with saving the lives of four pilots and their aircraft as of 2016. Future work is aimed at creating an Automatic Integrated Collision Avoidance System, which will also help prevent mid-air collisions [107].

Actual monitoring of a pilot's movement has been in place in combat aircraft for years via infrared beams. The Army's AH-64 Apache helicopter uses infrared sensors on either side of the pilot/gunner to detect movement of the pilot's head. This system is called the Integrated Helmet and Display Sight System, better known as IHADSS. It allows a computer to slew the

aircraft's gun to the pilot's monocle such that wherever the pilot/gunner is looking, the gun is pointed [108]. With a monocle already in place, one could also imagine an eye tracker looking back at the pilot to monitor the pilot's cognitive load and gradually assist in taking the workload off the pilot. It could do this by taking over critical systems of the aircraft, such as flying to avoid collision. Additionally it may even actively change displays in the cockpit in a manner which would help redirect the pilot's attention.

There are experimental research aircraft which currently employ some of these physiologic monitoring devices. At the University of Iowa's Operator Performance Laboratory, two Delfin L-29 jet aircraft are equipped with eye tracking devices as well as ECG monitors. Lead by Dr. Thomas Schnell, researchers there have developed software termed Cognitive Avionics Tool Set (CATS). This software imports on board data from physiologic sensors of the pilot in order to quantify human cognitive workload. Data analyzed include ECG, EEG, and eye tracking to name a few. Using CATS, operators on the ground can increase or decrease training scenarios based on how "overwhelmed" a subject is [109]. Further experimentation may be required to determine if cognitive decline due to hypoxia would also be detected by this system.

Currently the Royal Air Force (RAF) at the RAF Center of Aviation Medicine (CAM) also has jet aircraft with human physiologic monitoring capabilities. These aircraft are specially modified BAE Hawk T1 Mk1 aircraft, a platform similar to the U.S. Navy's T-45 Goshawk training aircraft. As a tandem aircraft, these jets are suited for research as the safety pilot-in-command operates the vehicle from the front seat while research subjects ride in the aft seat. Unfortunately, RAF CAM and its specially modified aircraft is scheduled to close by 2020 [110].

With all that has been discovered to date, there is also much more to be learned. By understanding current problems faced by pilots of 5th generation aircraft improved monitoring can take place. Monitoring can increase understanding of physiologic changes which occur as we push aircraft design into areas never before experienced by humans. By coupling monitors to automated systems which can "take over" when a pilot becomes incapacitated, human endurance can continue to be pushed to the limits in a safe manner.

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Conflict of interest

The authors have no conflict of interests to declare.

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References

- [1] Welcome to the Aerospace Medical Association [Internet]. Available from: <https://www.asma.org/for-the-public> [Accessed: Oct 1, 2017]
- [2] De Acosta J. Natural and Moral History of the East and West Indies 1604. Whitefish, Montana: Kessinger Publishing; 2003
- [3] Hack M, Vesel Z, Gariboldi L, Renshaw S, Ihara S, Fazlıoğlu İ, et al. Torricelli, Evangelista. Biographical Encyclopedia of Astronomers. New York, NY: Springer; 2007. pp. 1146-1147. DOI: 10.1007/978-0-387-30400-7_1390
- [4] Acott C. A brief history of diving and decompression illness. South Pacific Underwater Medicine Society. 1999;29(2):98-109
- [5] Davis JR, Johnson R, Stepanek J, Fogarty JA. Fundamentals of Aerospace Medicine. Philadelphia, Pennsylvania: Lippincott Williams & Wilkins; 2008. p. 2
- [6] The First Solo Flight: Jean-François Pilâtre de Rozier and the Marquis d'Arlandes [Internet]. 2009 Air & Space Magazine. Available from: <https://www.airspacemag.com/daily-planet/the-first-solo-flight-53893576/> [Accessed: Oct 1, 2017]
- [7] Davis J. Fundamentals of Aerospace Medicine. Philadelphia, Pennsylvania: Lippincott Williams & Wilkins; 2002
- [8] Bert P. Barometric Pressure: Researches in Experimental Physiology. Columbus, OH: College Book Company; 1943
- [9] Sept. 17, 1908: First Airplane Passenger Death [Internet]. Available from: <https://www.wired.com/2010/09/0917selfridge-first-us-air-fatality/> [Accessed: Oct 2, 2017]

- [10] Loening G. Takeoff into Greatness: How American Aviation Grew So Big So Fast. New York: Putnam; 1968
- [11] Jones D. Flying and dying in WWI: British aircrew losses and the origins of US military aviation medicine. *Aviation, Space, and Environmental Medicine*. 2008;**79**(2):139-146
- [12] Davis H. Generals in Khaki. Raleigh, North Carolina: Pentland Press Inc.; 1998
- [13] Elshatory Y, Siatkowski R. Wiley Post, around the world with no stereopsis. *Survey of Ophthalmology*. 2014;**59**(3):365-372. DOI: 10.1016/j.survophthal.2013.08.001
- [14] Miller R. Like a Thunderbolt: The Lafayette Escadrille and the Advent of American Pursuit in World War I. Washington, D.C.: Air Force History and Museums Program; 2007
- [15] Morgan R, Powers R. The Man Who Flew the Memphis Belle: Memoir of a WWII Bomber Pilot. New York: Penguin; 2001
- [16] Yeager C, Janos L. Yeager: An Autobiography. New York: Bantam Books; 1986
- [17] Mader T, Koch D, Manuel K, Gibson C, Effenhauser R, Musgrave S. Stability of vision during space flight in an astronaut with bilateral intraocular lenses. *American Journal of Ophthalmology*. 1999;**127**(3):341-343
- [18] Skaggs V, Norris A. Aerospace Medical Certification Statistical Handbook. Oklahoma City, Oklahoma: FAA Civil Aerospace Medical Institute, Administration FA; 2014. 2014 December 2015. Report No.: DOT/FAA/AM-15/22
- [19] Aviation Medical Examiner (AME) Training Federal Aviation Administration [Internet]. Available from: https://www.faa.gov/other_visit/aviation_industry/designees_delegations/designee_types/ame/ametraining/ [Accessed: Oct 1, 2017]
- [20] Residency Programs and Related Courses [Internet]. Available from: <https://www.asma.org/about-asma/careers/aerospace-medicine/residency-programs-related-courses> [Accessed: Oct 13, 2017]
- [21] Forces PA. Aircraft Accident Investigation: F-22A T/N 06-4125 JOINT BASE ELMENDORF-RICHARDSON ALASKA 16 NOVEMBER 2010. In: Force USA, editor
- [22] Settlement Reached in Haney F-22 Crash Lawsuit [Internet]. 2012. Available from: <https://www.flightglobal.com/news/articles/settlement-reached-in-haney-f-22-crash-lawsuit-375445/> [Accessed: Oct 1, 2017]
- [23] Brown J, Antunano M. Altitude-Induced Decompression Sickness. Oklahoma City, Oklahoma: Federal Aviation Administration, Civil Aerospace Medical Institute Aero-medical Education Division. AM-400-95/2; 1995
- [24] Signs and Symptoms of DCS [Internet]. Divers Alert Network. Available from: <https://www.diversalertnetwork.org/health/decompression/Signs-and-symptoms-of-DCS> [Accessed: Oct 1, 2017]

- [25] Krause K, Pilmanis A. The effectiveness of ground level oxygen treatment for altitude decompression sickness in human research subjects. *Aviation, Space, and Environmental Medicine*. 2000;**71**(2):115-118
- [26] McGuire S, Sherman P, Profenna L, Grogan P, Sladky J, Brown A, et al. White matter hyperintensities on MRI in high-altitude U-2 pilots. *Neurology*. 2013;**81**(8):729-735. DOI: 10.1212/WNL.0b013e3182a1ab12
- [27] McGuire S, Sherman P, Wijtenburg S, Rowland L, Grogan P, Sladky J, et al. White matter hyperintensities and hypobaric exposure. *Annals of Neurology*. 2014;**76**(5):719-726. DOI: 10.1002/ana.24264
- [28] McGuire S, Boone G, Sherman P, Tate D, Wood J, Patel B, et al. White matter integrity in high-altitude pilots exposed to hypobaria. *Aerospace Medicine and Human Performance*. 2016;**87**(12):983-988. DOI: 10.3357/AMHP.4585.2016
- [29] McGuire S, Tate D, Wood J, Sladky J, McDonald K, Sherman P, et al. Lower neurocognitive function in U-2 pilots: Relationship to white matter hyperintensities. *Neurology*. 2014;**83**(7):638-645. DOI: 10.1212/WNL.0000000000000694
- [30] Federal Aviation Administration. Introduction to Aviation Physiology. [Internet]. p. 3-3. Available from: https://www.faa.gov/pilots/training/airman_education/media/IntroAviationPhys.pdf [Accessed: Oct 23, 2017]
- [31] National Aeronautics and Space Administration. Loss of Signal: Aeromedical Lessons Learned from the STS-107 Columbia Space Shuttle Mishap [Internet]. 2014. Available from: <https://www.asma.org/asma/media/asma/Travel-Publications/NASA%20Shuttle/SP-2014-616.pdf> [Accessed: Oct 22, 2017]
- [32] Gillingham K, Wolfe J. Spatial Orientation in Flight. Texas: USAF School of Aerospace Medicine. Brooks Air Force Base; 1986. pp. 11-12
- [33] Voge V. Comparison of several G-tolerance measuring methods at various seatback angles. *Aviation, Space, and Environmental Medicine*. 1978;**49**(2):377-383
- [34] Burton R. Mathematical models for predicting G-duration tolerances. *Aviation, Space, and Environmental Medicine*. 2000;**71**(10):981-990
- [35] Protection Against the 'G' [Internet]. *Aviation Medicine: Aerospace Medicine*. Available from: <http://www.avmed.in/2012/06/protection-against-the-g/> [Accessed: Oct 1, 2017]
- [36] Wood E. Development of anti-G suits and their limitations. *Aviation, Space, and Environmental Medicine*. 1987;**58**(7):699-706
- [37] Wood E, Code C, Baldes E. Partial supination versus Gz protection. *Aviation, Space, and Environmental Medicine*. 1990;**61**(9):850-858
- [38] Burns J, Ivan D, Stern C, Patterson J, Johnson P, Drew W, et al. Protection to +12 Gz. *Aviation, Space, and Environmental Medicine*. 2001;**72**(5):413-421

- [39] Albery W. Acceleration in other axes affects +Gz tolerance: Dynamic centrifuge simulation of agile flight. *Aviation, Space, and Environmental Medicine*. 2004;**75**(1):1-6
- [40] Tacker W Jr, Balldin U, Burton R, Glaister D, Gillingham K, Mercer J. Induction and prevention of acceleration atelectasis. *Aviation, Space, and Environmental Medicine*. 1987;**58**(1):69-75
- [41] O'Brien J. Absorption atelectasis: Incidence and clinical implications. *American Association of Nurse Anesthetists*. 2013;**81**(3):205
- [42] Haswell M, Tacker W Jr, Balldin U, Burton R. Influence of inspired oxygen concentration on acceleration atelectasis. *Aviation, Space, and Environmental Medicine*. 1986;**57**(5):432-437
- [43] Lange B, Torp-Svendsen J, Toft P. Neck pain among fighter pilots after the introduction of the JHMCS helmet and NVG in their environment. *Aviation, Space, and Environmental Medicine*. 2011;**82**(5):559-563
- [44] Shiri R, Frilander H, Sainio M, Karvala K, Sovellius R, Vehmas T, et al. Cervical and lumbar pain and radiological degeneration among fighter pilots: A systematic review and meta-analysis. *Occupational and Environmental Medicine*. 2015;**72**(2):145-150. DOI: 10.1136/oemed-2014-102268
- [45] De Loose V, Van den Oord M, Burnotte F, Van Tiggelen D, Stevens V, Cagnie B, et al. Individual, work, and flight-related issues in F-16 pilots reporting neck pain. *Aviation, Space, and Environmental Medicine*. 2008;**79**(8):779-783
- [46] Verde P, Trivelloni P, Angelino G, Morgagni F, Tomao E. Neck pain in F-16 vs. typhoon fighter pilots. *Aerospace Medicine and Human Performance*. 2015;**86**(4):402-406. DOI: 10.3357/AMHP.4063.2015
- [47] Chumbley E, O'Hair N, Stolfi A, Lienesch C, McEachen J, Wright B. Home cervical traction to reduce neck pain in fighter pilots. *Aerospace Medicine and Human Performance*. 2016;**87**(12):1010-1015. DOI: 10.3357/AMHP.4625.2016
- [48] Four Ways Upgraded Ejection Seat Modifications Can Keep Our Pilots Safe [Internet]. The Washington Post. 2009. Available from: <http://www.washingtonpost.com/sf/brand-connect/wp/enterprise/four-ways-upgraded-ejection-seat-modifications-can-keep-our-pilots-safe/> [Accessed: Oct 1, 2017]
- [49] Ejection Seat Market Is Changing Pace [Internet]. 2017. Available from: <http://aviationweek.com/air-combat-safety/ejection-seat-market-changing-pace> [Accessed: Oct 12, 2017]
- [50] Collins R, McCarthy G, Kaleps I, Knox F. Review of major injuries and fatalities in USAF ejections, 1981-1995. *Biomedical Sciences Instrumentation*. 1997;**33**:350-353
- [51] Kang K-W, Shin YH, Kang S. Acute spinal injury after centrifuge training in asymptomatic fighter pilots. *Aerospace Medicine and Human Performance*. 2015;**86**(4):386-391. DOI: 10.3357/AMHP.4062.2015

- [52] Puderbaugh M. A report of transverse process fractures secondary to the centrifuge in a healthy aviator. *Aerospace Medicine and Human Performance*. 2016;**87**(7):655-658. DOI: 10.3357/AMHP.4541.2016
- [53] Kikukawa A, Tachibana S, Yagura S. G-related musculoskeletal spine symptoms in Japan Air Self Defense Force F-15 pilots. *Aviation, Space, and Environmental Medicine*. 1995;**66**(3):269-272
- [54] Lindgren T, Wieslander G, Dammström B, Norbäck D. Tinnitus among airline pilots: Prevalence and effects of age, flight experience, and other noise. *Aviation, Space, and Environmental Medicine*. 2009;**80**(2):112-116
- [55] Elmenhorst E, Elmenhorst D, Wenzel J, Quehl J, Mueller U, Maass H, et al. Effects of nocturnal aircraft noise on cognitive performance in the following morning: Dose-response relationships in laboratory and field. *International Archives of Occupational and Environmental Health*. 2010;**83**(7):743-751. DOI: 10.1007/s00420-010-0515-5
- [56] Rhee M, Kim H, Roh S, Kim H, Kwon H. The effects of chronic exposure to aircraft noise on the prevalence of hypertension. *Hypertension Research*. 2008;**31**(4):641-647. DOI: 10.1291/hypres.31.641
- [57] Rajguru R. Military aircrew and noise-induced hearing loss: Prevention and management. *Aviation, Space, and Environmental Medicine*. 2013;**84**(12):1268-1276
- [58] Department of Defense Office F-JP. F-35 Noise Measurement Executive Summary. [Internet] 2014. Available from: http://www.jsf.mil/news/docs/20141031_F-35_Noise_Executive_Summary.pdf [Accessed: Oct 13, 2017]
- [59] Newman E. Speech and hearing. In: Gray D, editor. *American Institute of Physics Handbook*. 3rd ed. New York: McGraw-Hill Book Co., Inc; 1957. pp. 3-155
- [60] Harris C, Shoenberger R. Combined effects of broadband noise and complex waveform vibration on cognitive performance. *Aviation, Space, and Environmental Medicine*. 1980;**51**(1):1-5
- [61] Griffin M. A comparison of standardized methods for predicting the hazards of whole-body vibration and repeated shocks. *Journal of Sound and Vibration*. 1998;**215**(4):883-914
- [62] El Falou W, Duchêne J, Grabisch M, Hewson D, Langeron Y, Lino F. Evaluation of driver discomfort during long-duration car driving. *Applied Ergonomics*. 2003;**34**(3):249-255
- [63] Smith S. Characterizing the effects of airborne vibration on human body vibration response. *Aviation, Space, and Environmental Medicine*. 2002;**73**(1):36-45
- [64] Bongers P, Hulshof C, Dijkstra L, Boshuizen H, Groenhout H, Valken E. Back pain and exposure to whole body vibration in helicopter pilots. *Ergonomics*. 1990;**33**(8):1007-1026
- [65] Gaydos S. Low back pain: Considerations for rotary-wing aircrew. *Aviation, Space, and Environmental Medicine*. 2012;**83**(9):879-889
- [66] Orlady W, Orlady M. *Human Factors in Multi-Crew Flight Operations*. Aldershot, England: Ashgate; 1999

- [67] Door R. *Air Combat: A History of Fighter Pilots*. New York, NY: The Berkley Publishing Group; 2006
- [68] Shetty J, Lawson C, Shahneh A. Simulation for temperature control of a military aircraft cockpit to avoid pilot's thermal stress. *CEAS Aeronautical Journal*. 2015;**6**(2):319-333
- [69] Robinson TSgt 1st MXG/MXQ. Department of Defense Langley Air Force Base Briefing: F-22 03-041 Stuck Canopy [Internet]. 2006. Available from: <http://www.spaceref.com/news/viewsr.html?pid=20396> [Accessed: Oct 1, 2017]
- [70] Nunneley S, Flick C. Heat stress in the A-10 cockpit: Flights over desert. *Aviation, Space, and Environmental Medicine*. 1981;**52**(9):513-516
- [71] Lee A. *Open Cockpit*. London, UK: Grub Street; 2012
- [72] Centers for Disease Control and Prevention Criteria for a Recommended Standard: Occupational Exposure to 1,1,2,2-Tetrachloroethane [Internet]. 1976. The National Institute for Occupational Safety and Health. Available from: <https://www.cdc.gov/niosh/nioshtic-2/00068146.html> [Accessed: Oct 1, 2017]
- [73] Heffter K. Industrial poisoning by tetrachloroethane. *Vierteljahresschr Gerichtl Med Oeff Sanitaetswes*. 1914;**48**:109-114
- [74] Willcox W, Spilsbury B, Legge T. An outbreak of toxic jaundice of a new type amongst aeroplane workers—Its clinical and toxicological aspect. *Transactions of the Medical Society of London*. 1915;**38**:129-156
- [75] Browning E. *Toxicity and Metabolism of Industrial Solvents*. 1st ed. New York: Elsevier; 1965
- [76] Harrison V, RS M. An emerging concern: Toxic fumes in airplane cabins. *Cortex*. 2016;**74**: 297-302. DOI: 10.1016/j.cortex.2015.11.014
- [77] Nicholas J, Butler G, Lackland D, Tessier G, Mohr L Jr, Hoel D. Health among commercial airline pilots. *Aviation, Space, and Environmental Medicine*. 2001;**72**(9):821-826
- [78] Bagshaw M. Health Effects of Contaminants in Aircraft Cabin Air: Summary Report v2.7. [Internet]. 2014. Available from: <https://www.asma.org/asma/media/asma/Travel-Publications/Air-contamination-health-effects-report-v2-7-Apr2014.pdf> [Accessed: Oct 1, 2017]
- [79] Hussain S, Frazier J. Cellular toxicity of hydrazine in primary rat hepatocytes. *Toxicological Sciences*. 2002;**69**(2):424-432
- [80] Latendresse J, Marit G, Vernot E, Haun C, Flemming C. Oncogenic potential of inhaled hydrazine in the nose of rats and hamsters after 1 or 10 1-hr exposures. *Toxicological Sciences*. 1995;**27**(1):33-48
- [81] National Institute for Occupational Safety and Health Guideline for Hydrazine: Potential Human Carcinogen [Internet]. 1988. Available from: <https://www.cdc.gov/niosh/docs/81-123/pdfs/0329.pdf> [Accessed: Oct 1, 2017]

- [82] Christensen W. Industrial hygiene and the F-16 air combat fighter. *Aviation, Space, and Environmental Medicine*. 1981;**52**(3):147-149
- [83] Sanlorenzo M, Wehner M, Linos E, Kornak J, Kainz W, Posch C, et al. The risk of melanoma in airline pilots and cabin crew: A meta-analysis. *JAMA Dermatology*. 2015; **151**(1):51-58. DOI: 10.1001/jamadermatol.2014.1077
- [84] Cadilhac P, Bouton M, Cantegril M, Cardines C, Gisquet A, Kaufman N, et al. In-flight ultraviolet radiation on commercial airplanes. *Aerospace Medicine and Human Performance*. 2017;**88**(10):947-951. DOI: 10.3357/AMHP.4852.2017
- [85] Band P, Spinelli J, Ng V, Moody J, Gallagher R. Mortality and cancer incidence in a cohort of commercial airline pilots. *Aviation, Space, and Environmental Medicine*. 1990;**61**(4): 299-302
- [86] Di Trollo R, Di Lorenzo G, Fumo B, Ascierio P. Cosmic radiation and cancer: Is there a link? *Future Oncology*. 2015;**11**(7):1123-1135. DOI: 10.2217/fon.15.29
- [87] Raslau D, Dabrh A, Moain A, Summerfield D, Wang Z, Steinkraus L, et al. Prostate cancer in pilots. *Aerospace Medicine and Human Performance*. 2016;**87**(6):565-570. DOI: 10.3357/AMHP.4453.2016
- [88] Ernsting J. The ideal relationship between inspired oxygen concentration and cabin altitude. *Aerospace Medicine*. 1963;**34**:991
- [89] United States Airforce Scientific Advisory Board: Aircraft Oxygen Generation SAB-TR-11-04 [Internet]. 2012. Available from: http://www.airforcemag.com/DocumentFile/Documents/2012/AFSAB_Oxygen_020112.pdf [Accessed: Oct 1, 2017]
- [90] Bumiller E. Oxygen Problems on F-22 Elude the Air Force's Fixes. *The New York Times*. July 2, 2012
- [91] Ferran L. F-22 Raptor, America's Most Expensive Fighter, Grounded Again After Oxygen Scare [Internet]. 2011. Available from: <http://abcnews.go.com/Blotter/22-raptor-grounded-oxygen-scare/story?id=14802706> [Accessed: Oct 1, 2017]
- [92] Fox News. US Navy grounds T-45 training fleet following Fox News Report [Internet]. 2017. Available from: <http://www.foxnews.com/politics/2017/04/05/us-navy-grounds-t-45-training-jet-fleet-following-fox-news-report.html> [Accessed: Oct 1, 2017]
- [93] CNN. F-35 fighters grounded indefinitely over oxygen issues [Internet]. 2017. Available from: <http://www.cnn.com/2017/06/12/politics/f-35-grounded-indefinitely-oxygen-problems/index.html> [Accessed: Oct 1, 2017]
- [94] West J. A strategy for in-flight measurements of physiology of pilots of high-performance fighter aircraft. *Journal of Applied Physiology*. 2013;**115**(1):145-149. DOI: 10.1152/japplphysiol.00094.2013
- [95] Flottman LCJ. Acceleration Atelectasis in the F-22 [Internet]. 2013. Chicago, IL: Aerospace Medicine Conference. Available from: http://asmameeting.org/asma2013_mp/pdfs/asma2013_present_510.pdf [Accessed: Oct 1, 2017]

- [96] McEachen J, Issa A, Marck J, Steinkraus L, Johnson B. Real-time effects of normobaric, transient near-anoxia on performance. *Aerospace Medicine and Human Performance*. 2015;**86**(2):76-81. DOI: 10.3357/AMHP.4041.2015
- [97] Hosseini S, Bruno J, Baker J, Gundran A, Harbott L, Gerdes J, et al. Neural, physiological, and behavioral correlates of visuomotor cognitive load. *Scientific Reports*. 2017;**7**(1): e8866. DOI: 10.1038/s41598-017-07897-z
- [98] Alnæs D, Sneve M, Espeseth T, Endestad T, van de Pavert S, Laeng B. Pupil size signals mental effort deployed during multiple object tracking and predicts brain activity in the dorsal attention network and the locus coeruleus. *Journal of Vision*. 2014;**14**(4):1-1
- [99] Stepanek J, Pradhan G, Cocco D, Smith B, Bartlett J, Studer M, et al. Acute hypoxic hypoxia and isocapnic hypoxia effects on oculometric features. *Aviation, Space, and Environmental Medicine*. 2014;**85**(7):700-707
- [100] Van Liere E, Stickney J. *Hypoxia*. Chicago and London: The University of Chicago Press; 1963
- [101] Marshall S. Identifying cognitive state from eye metrics. *Aviation, Space, and Environmental Medicine*. 2007;**78**(5):B165-B175
- [102] Albery W. Multisensory cueing for enhancing orientation information during flight. *Aviation, Space, and Environmental Medicine*. 2007;**78**(5):B186-B190
- [103] Thomas M, Russo M. Neurocognitive monitors: Toward the prevention of cognitive performance decrements and catastrophic failures in the operational environment. *Aviation, Space, and Environmental Medicine*. 2007;**78**(5):B144-B152
- [104] Tsai Y, Viirre E, Strychacz C, Chase B, Jung T. Task performance and eye activity: Predicting behavior relating to cognitive workload. *Aviation, Space, and Environmental Medicine*. 2007;**78**(5):B176-B185
- [105] Connolly D. Spatial contrast sensitivity at twilight: Luminance, monocularly, and oxygenation. *Aviation, Space, and Environmental Medicine*. 2010;**81**(5):475-483
- [106] Ernst G. Heart-rate variability – More than heart beats? *Frontiers in Public Health*. 2017; **5**:240. DOI: 10.3389/fpubh.2017.00240
- [107] Auto-GCAS Saves Unconscious F-16 Pilot-Declassified USAF Footage [Internet]. 2016. *Aviation Week & Space Technology*. Available from: <http://aviationweek.com/air-combat-safety/auto-gcas-saves-unconscious-f-16-pilot-declassified-usaf-footage> [Accessed: Oct 2, 2017]
- [108] Chait R, Lyons J, Long D. Critical Technology Events in the Development of the Apache Helicopter: Project *Hindsight* Revisited. Washington, DC: Center for Technology and National Security Policy; 2006. 27 p
- [109] Cognitive Avionics Toll Set (CATS) Software [Internet]. Available from: <https://hfddata.opl.uiowa.edu/opl/?q=cats> [Accessed: Oct 1, 2017]
- [110] BBC News. Ministry of Defence to sell 13 sites for 17,000 homes [Internet]. 2016. Available from: <http://www.bbc.com/news/uk-37287613> [Accessed: Oct 23, 2017]

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Musculoskeletal Injuries in the Military

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Kenneth L. Cameron • Brett D. Owens
Editors

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 Springer

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I would like to thank my family and colleagues who inspired and supported this project. This book is dedicated to them. This book is also dedicated to our military service members and their families who sacrifice so much in service to our nation. They deserve nothing less than the very best evidence-based injury prevention strategies and cutting edge health care for the musculoskeletal injuries and conditions that are commonly seen in this high-risk population.

—K.L.C.

I am grateful for the support of my family, who made this work possible. I thank my mother who taught me kindness and inspired me to lead a life of caring for others. I thank the soldiers for whom I have been fortunate to be able to care and from whom I have learned much.

—B.D.O.

Foreword

...the soldier, above all other people, prays for peace, for he must suffer and bear the deepest wounds and scars of war. —General Douglas MacArthur

More than 2 million soldiers, sailors, airmen, and marines were engaged in the longest continuous conflict in America's history. We were at war for more than 13 years, with an astonishingly high survival rate and relatively low amputation rate. I had the honor to serve as the orthopedic advisor (consultant) to the US Army surgeon general for 8 years of this war and to serve three surgeon generals. It was during the performance of this responsibility that I came to know Dr. Brett Owens and Dr. Kenneth Cameron. Brett completed his sports medicine fellowship during my early tenure and was finishing his study at the Institute for Surgical Research on the epidemiology of combat injuries. His subsequent seminal publications have garnered more than 500 citations—the most in all combat surgery literature—and are directly responsible for bringing public and medical attention to the vast burden of musculoskeletal disability currently facing our warriors. Ken has served as the Director of Orthopaedic Research for the John A. Feagin Jr. Sports Medicine Fellowship at the United States Military Academy at West Point and is a fervent scientist investigating ways to optimize human performance. Dr. Owens and Dr. Cameron have produced a body of independent research directed at better understanding the nature of these injuries and how to prevent them. Together, they have examined battle, non-battle, and training-related injuries, and in this new text, they present the cumulative American military expertise acquired during the past 15 years in the treatment and prevention of disability.

I am humbled and honored to introduce these scholars, who are respected and skilled clinicians, committed to best practices and prevention, and who are also world-renowned scientists in the field of sports- and combat-related trauma. In this text, they address the factors leading to high rates of morbidity and consider all aspects of the musculoskeletal system. They lead the students of military-related injuries on a tour of the body by system and region and then outline a systematic approach to prevention and mitigation of the impairments these patriots experience. I believe this text will inspire further investigation into the causes of and solutions to what represents the largest and longest-term burden facing the patriots who have served in contemporary volunteer military service.

The text is thoughtfully written by clinician-scientists with diverse perspectives—surgeons, rehabilitation specialists, and operationally oriented clinicians. Although amputations have been perhaps, the most visible reminder of the human cost of recent conflicts, non-battle injuries, as well as the high-performance sports—like joint injuries of the “tactical athlete” constitute even larger losses to the fighting forces. Additionally, and perhaps, a product of today’s more sedentary youth, injuries during initial entry training are more common and may be completely preventable. The discussion regarding stress fractures and overuse syndromes highlights this epidemic and is directly relevant to civilian sports medicine providers.

This fascinating text also tours the body, discussing gaps in treatment, prevention strategies, and types of impairments leading to losses of the fighting force. All contributing authors are specialty fellowship-trained practicing surgeons who have served in clinical practice, combat conditions, and academic centers, and who have broad expertise in their respective areas.

Finally, with contributions that promise to be practical, as well as influential, in both policy development and data-driven research funding, the final section assimilates these “combat subtractors” into several strategies for prevention, mitigation, and management. National health policy is increasingly focused on the critical examination of population-based health and what appears to be the indefinite future of the all-volunteer fighting force. The concepts and observations presented herein are leading from the front to direct thoughts on military medicine. This text is a must read for anyone committed to understanding the significance of musculoskeletal injuries experienced by our military and for the thought leaders who will be responsible for preventing and mitigating the sacrifices made by our warriors in the defense of our nation.

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Preface

Musculoskeletal injuries and conditions are endemic in US military populations. Former US Army Surgeon General, James Peake, referred to the burden of musculoskeletal injuries in the military as a “hidden epidemic” in 2000 [4]. Today, as the US military is transitioning from more than a decade of war on two fronts in the Middle East, new data suggest that this epidemic is emerging from the shadows [1–3]. Significant combat wounds, as well as non-battle injuries during deployment, have contributed to long-term disability and decreased quality of life in our veterans. This is, in addition, to the already high rates of training and sports-related injuries commonly observed in the young and active military population.

In this text, we have assembled a comprehensive panel of military and civilian clinicians and researchers with the primary objective of shedding some additional light on this “hidden” epidemic. Our goal was to produce an authoritative text on the epidemiology of musculoskeletal injuries and conditions typically seen in service members, utilizing the best data available to date. Clearly, some areas are still lacking in quality studies and supporting data—and we have solicited expert opinion in these cases. We have provided some general chapters on combat, noncombat, and sports and physical training-related injuries, as well as an anatomic breakdown of injury patterns commonly observed in military populations. In the final section, we have provided an overview of how the public health model has been applied to study and address the injury epidemic in the military and we have provided a framework for developing and implementing effective injury prevention strategies within this unique high-risk population. Our ultimate hope is to generate dialogue, research, and effective interventions that can be implemented in real-world settings to help mitigate the impact of musculoskeletal injuries and conditions among those who have committed to selflessly serve our nation.

References

1. Belmont PJ Jr., Goodman GP, Waterman B, DeZee K, Burks R, Owens BD. Disease and non-battle injuries sustained by a US Army Brigade Combat Team during Operation Iraqi Freedom. *Mil Med.* Jul 2010;175(7):469–76.
2. Goodman GP, Schoenfeld AJ, Owens BD, Dutton JR, Burks R, Belmont PJ. Non-emergent orthopaedic injuries sustained by soldiers in Operation Iraqi Freedom. *J Bone Joint Surg Am.* Apr 18 2012;94(8):728–35.
3. Owens BD, Kragh JF, Jr., Wenke JC, Macaitis J, Wade CE, Holcomb JB. Combat wounds in Operation Iraqi Freedom and Operation Enduring Freedom. *J Trauma.* Feb 2008;64(2):295–9.
4. Peake JB. Reflections on injuries in the military: the hidden epidemic. *Am J Prev Med.* Apr 2000;18(3 Suppl):4–5.

Contents

Part I The Spectrum of Musculoskeletal Injuries in the Military

1 The Burden of Musculoskeletal Injuries in the Military	3
Brett D. Owens and Kenneth L. Cameron	
2 Traumatic Combat Injuries	11
Andrew J. Schoenfeld and Philip J. Belmont	
3 The Burden of Deployment-Related Non-battle Injuries (NBIs) and Their Impact on the Musculoskeletal System	25
Kenneth L. Cameron	
4 Sports and Exercise-Related Injuries in the Military	43
Michael Garrison, Scott Dembowski, and Nathan Shepard	
5 Musculoskeletal Injuries During Military Initial Entry Training	61
Scott D. Carow and Jennifer L. Gaddy	
6 Disability Associated with Musculoskeletal Injuries	89
Chad A. Krueger and James R. Ficke	

Part II The Epidemiology of Musculoskeletal Injuries by Anatomic Region

7 Shoulder Injuries	105
Christopher J. Tucker and Brett D. Owens	
8 Elbow, Wrist, and Hand Injuries	123
Danielle L. Scher, Emily H. Shin, Jennifer M. Wolf, and Leon J. Nesti	
9 Hip Injuries	145
Joseph T. Lanzi and Steven J. Svoboda	

10 Knee Injuries	153
Jeremy McCallum and John M. Tokish	
11 Lower Leg, Ankle, and Foot Injuries	171
Brian R. Waterman, John Dunn, and Justin D. Orr	
12 Thoracic and Lumbar Spine Injuries	211
Jeffrey B. Knox and Joseph Orchowski	
13 Cervical Spine and Neck Injuries	229
Scott C. Wagner and Ronald A. Lehman	
 Part III Public Health Strategies for Injury Prevention and Treatment in the Military	
14 Application of the Public Health Model for Musculoskeletal Injury Prevention Within the Military	249
Kenneth L. Cameron	
15 Successful Injury Prevention Interventions	267
Sarah J. de la Motte and Robert Oh	
16 Overcoming Barriers to Injury Prevention in the Military	287
Deydre S. Teyhen, Stephen L. Goffar, Timothy L. Pendergrass, Scott W. Shaffer, and Nikki Butler	
Index	315

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Part I
The Spectrum of Musculoskeletal Injuries
in the Military

Chapter 1

The Burden of Musculoskeletal Injuries in the Military

Brett D. Owens and Kenneth L. Cameron

Introduction

Musculoskeletal injuries are endemic in the military. This is not surprising given that this population is extremely young and active compared with the general population. As such, musculoskeletal care is one of the most critical aspects of military medicine, and effective preventive and treatment approaches can significantly affect the readiness of the fighting forces. Injuries were highlighted as the “hidden epidemic” in 2000 by Peake [1]—and that was before 10 years of extended combat operations in Iraq and Afghanistan.

To date, the majority of the literature dedicated to military injuries has focused on the surgical treatment of complex wounds sustained in combat operations. However, these wounds (while devastating and important) can be viewed as the tip of the iceberg (see Fig. 1.1).

Below these devastating injuries (which are significantly fewer than in previous eras) lies a true iceberg of musculoskeletal injury and disease that plays a tremendous role in unit readiness and disability discharge. This book is intended to help shed some light on the full spectrum of this burden of musculoskeletal injuries and dysfunction in the military population.

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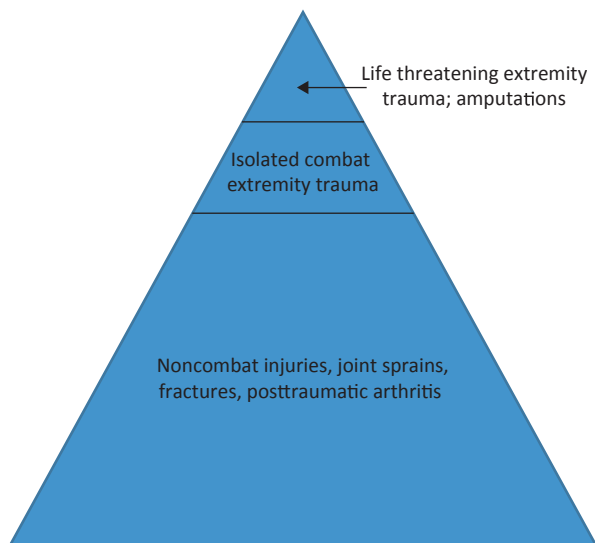


Fig. 1.1 The musculoskeletal injury “iceberg.” The “tip” comprises severe injuries and amputations that have received the most attention to date by the press, researchers, and funding sources. The “base” of the iceberg may be less severe and less visible but represents a larger burden of injury and disease

Combat and “Non-battle” Injuries

For most of the past decade, the US military has been engaged in two extended conflicts—Operation Iraqi Freedom (OIF) in Iraq and Operation Enduring Freedom (OEF) in Afghanistan. These two wars combined have resulted in thousands of deaths and injuries in tens of thousands, which is the greatest number of combat casualties since the Vietnam Conflict. Early in the course of these conflicts, there was an anecdotal appreciation for the significant burden of musculoskeletal combat wounds in this population; and eventually large-scale studies evaluating data from the Joint Theater Trauma Registry (JTTR) emerged confirming this trend [2, 3]. Not only did extremity battle wounds comprise 54 % of all wounds but a cost-utilization analysis found that musculoskeletal wounds also consumed 65 % of all inpatient care costs as well as 64 % of all disability costs and resulted in 64 % of all hospital readmissions [4, 5]. See Chap. 2 of this text for a more detailed description of the burden of combat-related musculoskeletal injuries in the military.

As a follow-up to the JTTR database studies, a large prospective cohort study followed a Brigade Combat Team (BCT) during a 15-month deployment to Iraq, allowing a comprehensive picture of mortality and wounding risk from the perspective of an individual unit [6]. While the combat battle injury data were consistent with previous studies from the JTTR [7], this study design allowed for an accurate evaluation of the non-battle injuries as well—those that are sustained in a deployed environment but not as the result of direct enemy contact. In previous wars, disease

and non-battle injuries (DNBI) have been as much or more of a burden on the military health-care system than true battle injuries. Similar to experiences in previous wars, the non-battle injuries resulted in far more medical evacuations from theater than the battle injuries. Furthermore, musculoskeletal injuries and conditions represented the greatest number and proportion of non-battle injuries and medical evacuations. Musculoskeletal injuries comprised 50 % of the DNBI casualties and 43 % of the DNBI casualties requiring evacuation [8]. Additionally, many service members sustained non-emergent musculoskeletal injuries, which are treated conservatively in theater and ultimately require surgery following their combat tour [8, 9]. The anterior cruciate ligament disruption and first-time shoulder dislocation incidence rates from non-battle injuries are nearly five times greater than that of the civilian population and similar to the endemic rates found in the non-deployed military population [10], and this is indicative of the daily rigors of the combat environment. A detailed description of the impact of noncombat musculoskeletal injuries and conditions during deployment is presented in Chap. 3 of this book.

Acute Traumatic Joint Injuries in Military Populations

As noted above, there is a great burden due to musculoskeletal injuries and conditions from combat wounds, as well as due to non-battle injuries in military populations. Non-battle musculoskeletal injuries and conditions are not only the greatest threat to combat readiness among soldiers deployed to Iraq and Afghanistan, but they also place a significant burden on the entire military population. Musculoskeletal injuries are endemic within military populations, and they pose the greatest public health problem facing military service members during both peacetime and combat operations. Musculoskeletal injuries and conditions are also the greatest threat to military readiness [11]. It is these injuries that occur during normal peacetime activity that were the focus of a series of studies conducted in order to better document the burden of musculoskeletal injury and disease as well as to help focus and plan prevention strategies.

Over the past decade, a series of population-based epidemiological studies utilizing data from the Defense Medical Surveillance System was performed to systematically evaluate the burden of musculoskeletal injuries and disorders affecting military service members [10, 12–29]. The initial focus was on acute traumatic joint injuries that typically lead to significant time loss from duty, morbidity, and the need for surgical intervention. The incidence rates for several specific musculoskeletal injuries were documented among active duty military service members, in addition to the demographic and occupational risk factors associated with these conditions. These data have been critical in defining the scope of the injury problem within the military, identifying the groups at highest risk for certain injuries, and have been helpful in targeting high-risk populations for injury prevention interventions.

The majority of musculoskeletal injuries seen in the military population are joint sprains and muscle strains and injury patterns that are similar to those observed in

athletic populations [30]. The anterior cruciate ligament in the knee has been shown to have an incidence rate that is an order of magnitude greater than the general population [10]. Similar endemic rates have been shown for ankle sprain [20] as well as shoulder instability [22]. These major joint sprains have significant impact on the soldiers' readiness, often resulting in recurrent sprain syndromes with deleterious effects on articular cartilage and joint homeostasis. The endemic rates make the study of joint sprain in this high-risk population extremely appealing in order to help determine both preventive measures and optimal treatment modalities [31]. The resultant posttraumatic osteoarthritis (OA) as well as the surveillance systems that are available also makes this an attractive population in which to study the outcomes of joint injury [32].

Degenerative Joint Disease in Military Populations

There is substantial evidence, in both animal and human studies, to support the link between traumatic joint injury and the subsequent occurrence of degenerative joint disease and OA. Because of the higher rates of joint injury observed among military populations and the significant occupational and physical training demands in this population, similar studies were conducted using data from the Defense Medical Surveillance System and the JTTR to examine the incidence rate and burden of OA among military service members. These reports found that the incidence rate for OA was significantly higher in every age group among military service members and that the disparity between military service members and the general population increased with increasing age [13].

In a separate study, the incidence of hip OA among active duty military service members was examined [17]. The overall incidence rate for males was 35 cases per 100,000 person-years, with rates ranging from 32 cases per 100,000 person-years among males to 54 cases per 100,000 person-years among females. While incidence rates for hip OA were lower than previously reported in the literature, this is likely because the majority of published studies have focused on the incidence of OA in much older study populations. The observed incidence rates for hip OA in this relatively young and healthy population are disconcerting and combined with the overall rates for OA in comparison to the general population raise concerns about the burden of OA in load-bearing joints following military service.

Cross et al. [33] reviewed physical evaluation board records for disability discharge among military service members and noted that orthopaedic and musculoskeletal injuries resulted in the majority of long-term disabilities in this study cohort. They also reported that degenerative arthritis was the leading cause of disability discharge from military service in this population and was the third most significant in terms of impact (e.g., frequency $\times$ average percent disability). The advanced rate of posttraumatic OA was alarming with many service members progressing to OA within a couple of years following acute traumatic injury. The long-term burden in terms of health-care costs and disability-adjusted life years in this cohort will be

significant into the future, and concerted efforts are needed to improve the quality of care and life for these veterans.

Anatomy of an Epidemic

The people who serve in the military represent many things. But one aspect is undisputed...they are young and active. Their activity levels are similar to other athletic populations with the addition of combat training and actual combat, which has been referred to as the ultimate contact sport. In all of these endeavors, from recreational sports and physical fitness to actual combat wounds, musculoskeletal injuries predominate. The activity demands along with these endemic injury rates mean that the care of these musculoskeletal injuries has a huge impact on force readiness as well as service retention and disability. All of these factors combined contribute to musculoskeletal injury rates of epidemic proportions within the military population. The unique military environment is also well positioned for epidemiologic work, treatment-outcome studies to evaluate the comparative effectiveness of various treatment strategies for common musculoskeletal injuries, and preventive strategies that have the potential for significant impact on both the military forces and civilian populations with similar characteristics.

The “anatomy” of this musculoskeletal injury epidemic can be viewed in multiple ways. One perspective is to detail the extreme burden of musculoskeletal injuries in every phase of military activity. This chapter provides an overview of this literature, and further details are provided in the following four chapters of this book. The areas covered are traumatic combat injuries as well as an assessment of deployment-related non-battle injuries and musculoskeletal disease. A chapter on sports and exercise-related injuries details the injury ramifications of maintaining a fit fighting force, even in peacetime. Finally, a chapter on initial entry training or basic training injuries completes the picture, as the factors that contribute to musculoskeletal injuries in this training environment are unique and provide insights into many athletic training and performance endeavors within the military.

Another perspective on how to describe the “anatomy” of the musculoskeletal injury epidemic in the military is to detail the injury burden by each respective body region...a true anatomic viewpoint. When approached this way, we are able to drill down to the types of musculoskeletal injuries and conditions that are most significant and have the greatest impact on the military population by each anatomic region. The following seven chapters are thus organized into respective body regions focusing on these areas of greatest injury and musculoskeletal disease burden within the military. These authors are a “Who’s Who” of military orthopaedic surgery—the experts each in their lane of injury with expertise from the combat theater to the military medical center state side.

The final section represents the future of musculoskeletal injury research and prevention in the military from a public health perspective. Three chapters are included in the hopes of stimulating discussion and possibly the integration of primary

and secondary prevention techniques within the high-risk military population. We intend to highlight the application of the public health model for musculoskeletal injury prevention in the military as well as some successes of injury prevention, but also to illuminate the potential barriers to successful implementation and provide potential strategies to overcome these barriers in a military environment. The burden of musculoskeletal injuries in the military is daunting, instead it can also be seen as a tremendous opportunity with which to learn about musculoskeletal injury and disease in a high-risk cohort. Successful primary and secondary preventive strategies would be welcomed in this endemic population and could possibly serve to benefit the civilian population at large in the areas of musculoskeletal injury prevention, treatment, and research.

Summary

Musculoskeletal injuries are endemic in the military population. While the focus has recently been on severe combat wounds, the burden of noncombat injuries affects both unit readiness and future disability for service members. Future research endeavors will hopefully better illuminate the risk factors for sprains, strains, and even OA in this active population. With this information, effective injury prevention strategies can be developed and implemented within the military to reduce the impact of musculoskeletal injuries and diseases on military readiness. A focus on primary prevention is critical to mitigate the potential long-term consequences of long-term disability and degenerative joint disease in active duty service members and veterans of military service.

Disclaimer All authors are employees of the US Federal Government and the US Army. The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or reflecting the views of the US Army, the Department of Defense, or US government.

References

1. Peake JB. Reflections on injuries in the military: the hidden epidemic. *Am J Prev Med.* 2000;18:4–5.
2. Owens BD, Kragh JF Jr, Wenke JC, Macaitis J, Wade CE, Holcomb JB. Combat wounds in Operation Iraqi Freedom and Operation Enduring Freedom. *J Trauma.* 2008;64:295–9.
3. Owens BD, Kragh JF Jr, Macaitis J, Svoboda SJ, Wenke JC. Characterization of extremity wounds in Operation Iraqi Freedom and Operation Enduring Freedom. *J Orthop Trauma.* 2007;21:254–7.
4. Masini BD, Waterman SM, Wenke JC, Owens BD, Hsu JR, Ficke JR. Resource utilization and disability outcome assessment of combat casualties from Operation Iraqi Freedom and operation Enduring Freedom. *J Orthop Trauma.* 2009;23:261–6.
5. Masini BD, Owens BD, Hsu JR, Wenke JC. Rehospitalization after combat injury. *J Trauma.* 71:S98–102.

6. Belmont PJ Jr, Goodman GP, Zacchilli M, Posner M, Evans C, Owens BD. Incidence and epidemiology of combat injuries sustained during “the surge” portion of operation Iraqi freedom by a US Army Brigade Combat Team. *J Trauma*. 68:204–10.
7. Belmont PJ Jr, Thomas D, Goodman GP, et al. Combat musculoskeletal wounds in a US Army Brigade Combat Team during operation Iraqi Freedom. *J Trauma*;71:E1–7.
8. Belmont PJ Jr, Goodman GP, Waterman B, DeZee K, Burks R, Owens BD. Disease and nonbattle injuries sustained by a US Army Brigade Combat Team during operation Iraqi freedom. *Mil Med*. 175:469–76.
9. Goodman GP, Schoenfeld AJ, Owens BD, Dutton JR, Burks R, Belmont PJ. Non-emergent orthopaedic injuries sustained by soldiers in Operation Iraqi Freedom. *J Bone Joint Surg Am*. 94:728–35.
10. Owens BD, Mountcastle SB, Dunn WR, DeBerardino TM, Taylor DC. Incidence of anterior cruciate ligament injury among active duty U.S. military servicemen and servicewomen. *Mil Med*. 2007;172:90–1.
11. Jones BH, Canham-Chervak M, Sleet DA. An evidence-based public health approach to injury priorities and prevention recommendations for the U.S. military. *Am J Prev Med*. 38:S1–10.
12. Blank E, Belmont PJ, Burks R, Sturdivant RX, Owens BD. Incidence of trochanteric bursitis in the US military. *Orthopedics*. (In Press).
13. Cameron KL, Hsiao MS, Owens BD, Burks R, Svoboda SJ. Incidence of physician-diagnosed osteoarthritis among active duty United States military service members. *Arthritis Rheum*. 63:2974–82.
14. Wolf JM, Dawson L, Mountcastle SB, Owens BD. The incidence of scaphoid fracture in a military population. *Injury*. 2009;40:1316–9.
15. Wolf JM, Mountcastle S, Owens BD. Incidence of carpal tunnel syndrome in the US military population. *Hand (N Y)*. 2009;4:289–93.
16. Wolf JM, Sturdivant RX, Owens BD. Incidence of de Quervain’s tenosynovitis in a young, active population. *J Hand Surg Am*. 2009;34:112–5.
17. Scher DL, Belmont PJ Jr, Mountcastle S, Owens BD. The incidence of primary hip osteoarthritis in active duty US military servicemembers. *Arthritis Rheum*. 2009;61:468–75.
18. Scher DL, Belmont PJ Jr, Bear R, Mountcastle SB, Orr JD, Owens BD. The incidence of plantar fasciitis in the United States military. *J Bone Joint Surg Am*. 2009;91:2867–72.
19. Scher DL, Owens BD, Sturdivant RX, Wolf JM. Incidence of joint hypermobility syndrome in a military population: impact of gender and race. *Clin Orthop Relat Res* 2010;468:1790–5.
20. Cameron KL, Owens BD, DeBerardino TM. Incidence of ankle sprains among active duty members of the United States armed services between 1998–2006. *J Athl Tr*. 2010;45:29–38.
21. Owens B, Mountcastle S, White D. Racial differences in tendon rupture incidence. *Int J Sports Med*. 2007;28:617–20.
22. Owens BD, Dawson L, Burks R, Cameron KL. Incidence of shoulder dislocation in the United States military: demographic considerations from a high-risk population. *J Bone Joint Surg Am*. 2009;91:791–6.
23. Wolf JM, Mountcastle S, Burks R, Sturdivant RX, Owens BD. Epidemiology of lateral and medial epicondylitis in a military population. *Mil Med*. 175:336–9.
24. Hsiao M, Owens BD, Burks R, Sturdivant RX, Cameron KL. Incidence of acute traumatic patellar dislocation among active-duty United States military service members. *Am J Sports Med*. 38:1997–2004.
25. Jones JC, Burks R, Owens BD, Sturdivant RX, Svoboda SJ, Cameron KL. Incidence and risk factors associated with meniscal injuries among active-duty US military service members. *J Athl Train*. 47:67–73.
26. Knox J, Orchowski J, Scher DL, Owens BD, Burks R, Belmont PJ. The incidence of low back pain in active duty United States military service members. *Spine (Phila Pa 1976)*. 36:1492–500.
27. Knox JB, Orchowski JR, Owens B. Racial Differences in the incidence of acute low back pain in US military service members. *Spine (Phila Pa 1976)*.

28. Ernat J, Knox JB, Orchowski JR, Owens BD. Incidence and risk factors for acute low back pain in active duty infantry. *Mil Med.* (In Press).
29. Hsiao MS, Cameron KL, Huh J, Hsu JR, Benigni M, Owens BD. Incidence and epidemiology of clavicle fracture in the United States military. *Mil Med.* (In Press).
30. Cameron KL, Owens BD. The burden and management of sports-related musculoskeletal injuries and conditions within the US military. *Clin Sports Med.* 2014;33(4):573–89.
31. Cameron KL, Mountcastle SB, Nelson BJ, et al. History of shoulder instability and subsequent injury during four years of follow-up: a survival analysis. *J Bone Joint Surg Am.* 2013;95:439–45.
32. Svoboda SJ, Harvey TM, Owens BD, Brechue WF, Tarwater PM, Cameron KL. Changes in serum biomarkers of cartilage turnover after anterior cruciate ligament injury. *Am J Sports Med.* 2013;41:2108–16.
33. Cross JD, Ficke JR, Hsu JR, Masini BD, Wenke JC. Battlefield orthopaedic injuries cause the majority of long-term disabilities. *J Am Acad Orthop Surg*;19 Suppl 1:S1–7.

Chapter 2

Traumatic Combat Injuries

Andrew J. Schoenfeld and Philip J. Belmont

Introduction

Prior to the modern era, it would have been paradoxical to speak of a “burden” of combat-related musculoskeletal wounds within the military. Before the advent of the all-volunteer force following the Vietnam conflict, personnel who sustained musculoskeletal injuries in combat either recuperated and returned to the battlefield or were administratively separated from the service [1]. The professional cadre of the armed forces was comparatively small at the time and, given this fact as well as limitations inherent in the scope of surgical care and rehabilitation, opportunities for cumulative injuries to accrue were restricted. In addition, it should be appreciated that in the time before 1941 the vast majority of survivable war wounds involved the musculoskeletal system, and nearly all injuries severe enough to necessitate emergent medical care obviated the potential for further military service [1].

Over the last half-century, however, advances in personnel protective equipment, medical evacuation, and surgical care have culminated in the fact that besides being survivable, most battle injuries can be treated to the point where there is at least the possibility of a return to duty [2, 3]. This, combined with an enhanced desire among the professional fighting force to avoid medical separation, has resulted in the functional restoration and retention of countless service members, including amputees, who may not have even survived their injuries had they occurred in earlier conflicts [1, 2, 4–6].

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11

At the time of writing this chapter, the wars in Iraq (2003–2011) and Afghanistan (2001–present) have produced approximately 50,000 wounded American personnel [7] which, if recent data may be extrapolated [8], could represent as many as 39,000 service members with one or more musculoskeletal injuries. Soldiers with combat military occupational specialty (MOS) designations are likely at greater risk of sustaining more than one musculoskeletal injury per casualty-inducing event (Schoenfeld et al., unpublished data) with incidence rates of multisystem orthopedic trauma (e.g., axial skeleton and extremities) exceeding 50 % in the most severely wounded personnel [9]. It is important to understand the combat-related context from which such injuries are derived, as well as the novel injury mechanisms and wounding patterns that have occurred as a result. These are not only essential to more completely appreciate the burden of musculoskeletal wounds that will persist in active duty military personnel for years to come, but they can also inform expected caseloads within the veterans administration system as well as the types of casualties that may occur in future conflicts [8, 10, 11].

Incidence Rates and Epidemiology of Combat Musculoskeletal Wounds

In contrast to previous military engagements, a robust quantity of published data now exists to facilitate determinations of expected musculoskeletal casualty rates for deployed medical assets [12] and maneuver-units [13–15] as well as for the Iraq and Afghanistan wars as a whole [8–10, 16–20]. Reports dedicated to the experiences of combat units [13–15], or to the forward surgical teams (FSTs) and combat support hospitals (CSHs) that follow in their wake [12], are highly influenced by the type of military assignment and degree of exposure to the combat environment. Multiyear evaluations, conducted using military databases such as the Department of Defense Trauma Registry (DoDTR) [8, 10, 16, 18, 19] or the Armed Forces Medical Examiner System (AFMES) [9, 15, 17], may be able to provide more holistic appreciations regarding the extent of combat-related musculoskeletal trauma, albeit confined to the theater(s) under consideration. Composite efforts, employing Defense Manpower Datacenter (DMD) statistics to calculate populations at risk [8, 10] or focusing on combat-specific military personnel [19], enable a more refined perspective regarding the nature of musculoskeletal war trauma that potentially has prognostic value. Alternatively, studies performed during certain phases of a conflict (e.g., maneuver phase of Operation Iraqi Freedom (OIF) from March to May 2003, or active counterinsurgency during Iraq war troop surge 2006–2007) may inform the kinds of casualties that may arise from similar engagements. It has been proposed that Operation Enduring Freedom (OEF) be considered representative of a modern asymmetric conflict and OIF commensurate with combat in a largely urban environment [9, 19].

The earliest medical publications from the wars in Iraq and Afghanistan involved the experiences of FSTs that had deployed in support of the maneuver phase of OIF

and OEF, or CSHs that were established early on in Kandahar, Bagram, or Baghdad [21]. Although most studies reported a preponderance of extremity injuries among the combat wounds encountered, no casualty rates or estimates regarding the incidence of wounding patterns could be calculated as a result of temporal limitations, low frequencies of casualties, and unknown populations at risk. In 2007, Owens et al. published their landmark effort, the first study to catalog the extent of extremity wounds in Iraq and Afghanistan over an extended period of time (2001–2005) [18]. That investigation was unable to postulate determinations for the incidence of such injuries, however, primarily due to unknown deployment data for the period under consideration. Nonetheless, Owens and coworkers showed that the rate of extremity wounds, as a percentage of all deployment-related injuries, was comparable to previous wars, including World War II, Korea, and Vietnam [18]. The prevalence of fractures among all extremity wounds was also similar to figures for both Vietnam and Korea [18].

In 2011, Belmont et al. became the first to publish epidemiological data on combat-related musculoskeletal trauma derived using a known population at risk [14]. This investigation, which prospectively followed a single Army Brigade Combat Team over the course of a 15-month deployment to Iraq, determined a musculoskeletal casualty rate of approximately 34 soldiers per 1000 personnel deployed per year [14]. The percentage of extremity injuries (49%), as compared to all combat-related trauma [14], was found to be slightly lower than the metric posited in the work of Owens' group [18] and represented the lowest estimate for the rate of such wounds in the last 60 years of American warfare.

A subsequent study, performed using DoDTR information and deployment statistics from the DMD, maintained that the percentage of extremity injuries among all wounds was 52%, while the incidence of musculoskeletal combat casualties was 3 per 1000 [8]. These conflicting findings readily illustrate the difficulties inherent in combat casualty research and the influence of study-design and inclusion criteria on results. While the DoDTR contains details regarding all military casualties, regardless of MOS (e.g., combat specific vs. combat support) or branch of service (e.g., Army and Marine service members with intense combat experience, as well as Navy and Air Force personnel with less regular exposure to battle), the work of Belmont and colleagues [14] was focused on a basic combat unit of the Army, serving in Iraq during some of the most intense periods of the OIF *Troop Surge*. Thus, the investigation of Belmont et al. [14] likely has more predictive value for other maneuver or combat-specific units, while the global effort derived using the DoDTR [8] may only be applicable to the armed forces as a whole.

Although devastating musculoskeletal injuries that occur in combat and result in medical evacuation or death are highly visible to medical professionals and to the public, a much larger volume of musculoskeletal trauma accrues in service members who are injured, yet still complete their deployment [4, 11, 22]. Many of these wounds result from repetitive musculoskeletal injuries and are more commensurate with civilian orthopedic, or sports medicine, injuries such as superior labrum anterior to posterior (SLAP) lesions, Bankart lesions, or meniscal tears [11]. Goodman et al. estimated that such combat-related “nonemergent” musculoskeletal trauma

occurred in approximately 17 of every 1000 soldiers deployed to a combat theater [11].

Wounding Mechanisms

Explosive blast has consistently been found to be the predominant mechanism of injury in Iraq and Afghanistan, continuing a trend that began at the start of the twentieth century [1, 8, 13]. Prior to the advent of gunpowder, most battlefield wounds generated by swords, spears, or axes were associated with low survival rates [1]. The widespread introduction of gunpowder in the sixteenth century quickly rendered shot (either musket or artillery) the most common cause of wounds. Although the numbers of war casualties consequently increased, the case fatality rate for battlefield injuries also diminished. Gunshot, grapeshot, or artillery shrapnel were the predominant progenitors of injury through the mid-nineteenth century, with the Civil War representing the last major American engagement where less than 10% of casualties occurred as a result of explosive mechanisms (Fig. 2.1). Beginning with World War I, the prevalence of injuries related to explosive blast has exceeded 30%, with such wounds outpacing those precipitated by gunshot for every conflict since World War II [1, 8, 10, 13, 14, 18].

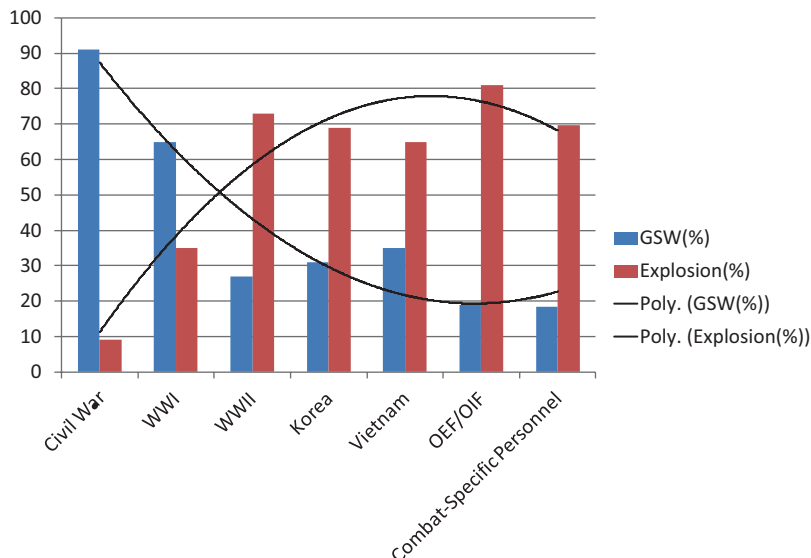


Fig. 2.1 Historical comparison of wounding patterns by conflict for major military engagements of the USA from the Civil War (1861–1865) to the present. Data for combat-specific personnel are derived from the Iraq and Afghanistan conflicts as reported by Schoenfeld et al. [19]. *WWI* World War I, *WWII* World War II, *OEF* Operation Enduring Freedom, *OIF* Operation Iraqi Freedom, *GSW* gunshot wound

Explosive mechanisms of injury, including improvised explosive device (IED), explosively formed projectiles, rocket-propelled grenade, and landmine, have been found to account for 75–81 % of all musculoskeletal casualties incurred in Afghanistan or Iraq [8–10, 13–16, 18–21], although the rate may be 10–20 % lower among soldiers killed in action [9] and among those directly engaged in combat [19]. The destructive force of these explosive devices creates severely contaminated soft-tissue and osseous wounds, particularly involving the extremities, in dismounted personnel (Fig. 2.2) [2, 3, 23–26]. While armor-enhanced vehicles provide more protection for vital organs and extremities, the shock wave precipitated by the blast has been associated with injury to the axial skeleton [27, 28], creating characteristic wound patterns such as low lumbar burst fractures [29] and lumbopelvic dissociation [30]. An increased enemy reliance on explosive devices in Afghanistan and Iraq has also culminated in an elevation in major amputations as compared to other modern wars, with current figures for such injuries hearkening back to rates encountered during the Vietnam era [14, 15, 20]. Even in the event that these devastating wounds can be reconstructed, limbs salvaged, or those with amputations fitted with state-of-the-art prostheses, the extent of soft-tissue damage and wound contamination associated with the initial explosive event results in a high propensity for wound-related complications to develop in the long term, including heterotopic ossification [31], osteomyelitis [24, 32], and soft-tissue contractures.

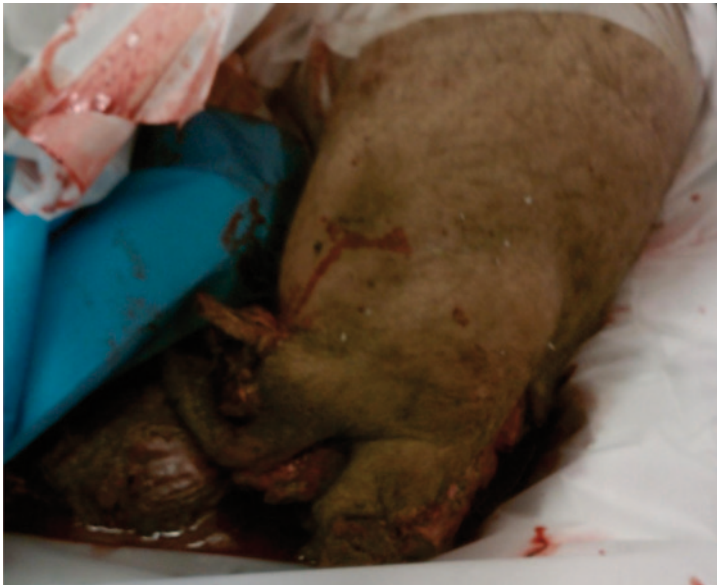


Fig. 2.2 Left leg traumatic amputation that occurred as a result of improvised explosive device (IED) blast in a dismounted soldier. The soldier also sustained right lower extremity soft-tissue wounds, abdominal injuries, and lumbopelvic dissociation. He succumbed to his injuries during emergency surgery performed in theater

Combat-Related Injuries and Wounding Patterns

The aforementioned work of Belmont et al., conducted among soldiers from a single brigade combat team deployed to Iraq, identified soft-tissue or neurovascular injuries as the most frequent musculoskeletal wound, occurring in 33 of every 1000 soldiers deployed per year (Fig. 2.3) [14]. Closed fractures were identified in 6 per 1000, while open fractures were reported in 5 per 1000. A more refined analysis, conducted using data from the DoDTR, confirmed that nearly 50% of all musculoskeletal wounds involved the soft tissues [8]. In this investigation, fractures represented 40% of all injuries, with those involving the tibia/fibula (7%) and foot



Fig. 2.3 Right upper extremity wound sustained during combat in Iraq. This injury was associated with a traumatic laceration involving the brachial artery

(5%) as the most frequent [8]. Among several others [4, 5, 9, 10, 15, 17, 19–21, 23], Belmont's study also highlighted a comparatively elevated rate of major amputations, pelvic trauma, and injuries to the spine [8].

Combat-related amputations, which are nearly entirely attributable to explosive mechanisms of injury, have been found to represent anywhere from 4 to 11% of all musculoskeletal wounds in the current conflicts [8, 14, 20, 23]. Stansbury et al. claimed that major limb amputations (those occurring proximal to the wrist or ankle joints) comprised 5% of all serious war injuries and 7% of major wounds involving the extremities [20]. These authors also contended that 18% of all amputees had more than one extremity amputation and 2% had amputations involving both the upper and lower extremities [20]. The Army Dismounted Complex Blast Injury Task Force reported that the amputation rate among Marine Corps personnel was 1 in 206, a metric markedly higher than that encountered for Army soldiers (1 in 641) [23].

Pelvic fractures have been identified in nearly 30% of soldiers who were killed in action, with most wounds presenting as a result of IEDs [17]. Davis et al. maintained that combat-related pelvic trauma was associated with low survival (10%), citing major hemorrhage or the combination of shock and associated head injuries as the leading cause of mortality [17]. Ramasamy and colleagues published similar results in their series of 29 consecutive patients treated for open blast-related injuries to the pelvis [26]. While the incidence of war wounds to the pelvis has not systematically been quantified, Belmont et al. reported that 2% of all musculoskeletal injuries sustained in battle consisted of pelvic and acetabular fractures [8].

Spinal wounds occurring as a result of combat have repeatedly been found to be present at some of the highest rates in American military history during the wars in Afghanistan and Iraq [9, 15, 16, 21]. Schoenfeld et al., examining the incidence of combat-related spinal injury in a brigade combat team, documented a rate of 7% [15] that approximates the near 6% incidence reported by Blair and colleagues in their longitudinal investigation using the DoDTR [16]. In another work that considered spinal injury data encountered among soldiers killed in theater, Schoenfeld and colleagues published an astonishing 39% prevalence [9] that, when combined with the data presented by Blair et al. [16] (which excluded service members killed in theater), yields an overall estimate of 12% for spinal trauma during the current conflicts [9]. Most spinal injuries that transpire as a result of battle seem to be commensurate with civilian spine trauma, including transverse process fractures, compression injuries, and burst fractures [9, 15, 16, 21]. A higher rate of neurologic injury (Fig. 2.4) and penetrating wounds to the cervical region have been encountered, however, particularly when compared to studies confined to civilian populations [9, 16, 21, 33]. The rate of spinal cord injury among survivors appears to be in the range of 10–20% [8, 15, 16], while this figure may be as high as 50% in soldiers with spine trauma who succumb to their wounds [9]. The low survivability associated with penetrating cervical spine wounds in the setting of neurologic injury has led some authors to consider such personnel as expectant in the combat environment.

Relatively rare spinal injuries, such as lumbopelvic dissociation and atlanto-occipital injury, are also seen with increased frequency among combat-injured sol-



Fig. 2.4 Axial computed tomographic image of a soldier who sustained a gunshot wound to the L1 vertebrae. Besides an L1 vertebral body fracture, the bullet traversed the spinal canal precipitating a conus medullaris syndrome

diers [9]. Schoenfeld et al. reported that atlanto-occipital injury was present in 10% of soldiers killed in theater, while low-lumbar vertebral fractures were identified in 26% and lumbopelvic dissociation in 2% [9]. In a retrospective review of 15 soldiers with lumbopelvic dissociation treated at Walter Reed Army Medical Center, Helgeson et al. reported that nearly all such injuries occurred as a result of explosive blast mechanisms and were significantly associated with severe wounds in other body regions [30]. Internal fixation was obviated in many instances due to the poor condition of overlying soft tissues, although when stabilization could be achieved, faster mobilization and earlier union were found to result [30]. Similar to other reports documenting outcomes following internal fixation for war trauma, these authors encountered a 13% infection rate among those soldiers who were treated with spinal instrumentation [30].

Comparatively few works have focused on battle wounds to body regions outside of the axial skeleton, although some information regarding hand injuries is available. Fractures involving the hand comprised 5% of all extremity injuries in the work of Owens et al. [18], and similar values were appreciated in the studies performed by Belmont and colleagues using unit-specific data [14] as well as the

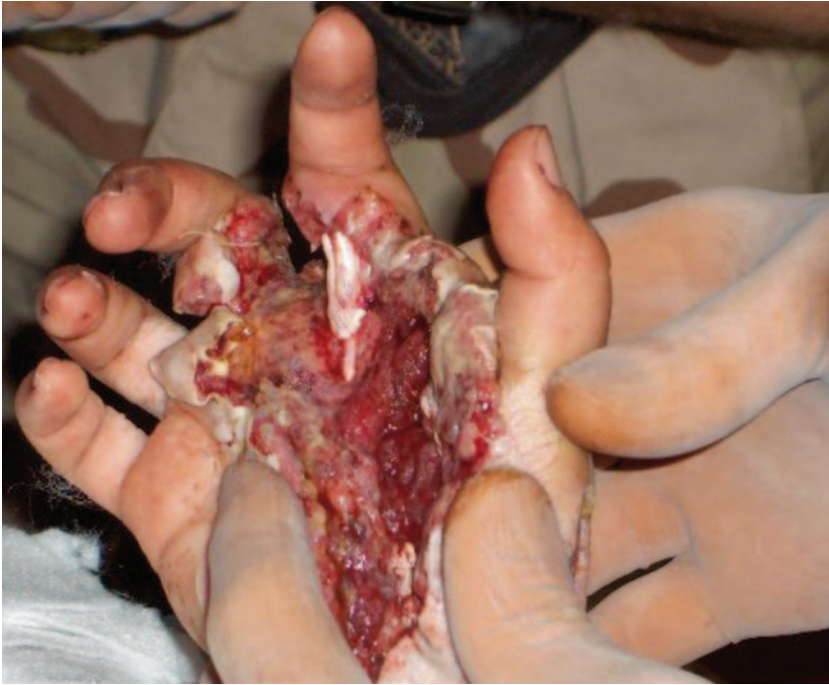


Fig. 2.5 High-velocity gunshot wound to the hand sustained by a soldier in Iraq

DoDTR [8]. A British military investigation, considering isolated deployment-related hand trauma from 2003 to 2009, reported that 73 % of 414 hand wounds required operative intervention (Fig. 2.5), with a plurality necessitating wound management, and 30% some degree of internal fixation [31]. Nerve or tendon repairs were required in 23 % of cases.

Outcomes and the Cumulative Burden of Combat-Related Musculoskeletal Injuries

Despite the enhanced lethality of the weapons employed by the enemies of the USA in the wars in Afghanistan and Iraq, advances in personnel protective equipment, armored vehicles, evacuation capacity, and modern medicine have resulted in the fact that the case fatality rate for these wars is the lowest in history [2, 3, 8, 19]. Although most soldiers are surviving wounds that would have proved fatal only a few decades earlier, their extensive injuries often necessitate multiple surgical interventions and prolonged periods of rehabilitation.

Among a series of 1333 combat-injured soldiers, Masini et al. estimated that the cost of immediate care approached US\$66 million, with 65 % of all resource

expenditures devoted to the care of extremity wounds [5]. Extrapolated to the number of American casualties generated from the start of the Afghanistan war through mid-2008, these authors maintained that the cost of combat-related healthcare exceeded US\$700 million, with a further US\$1.2 billion necessary to cover benefits related to disabilities [5]. Indeed, it has been proposed that as many as 35% of combat-wounded who are medically evacuated from theater will be ultimately rendered unfit by their injuries to remain in active duty service [4, 5]. Musculoskeletal injuries sustained during deployment likely account for the medical separation of 6% of a combat unit's deployment strength (Schoenfeld et al., unpublished data), a figure double what can be expected through attrition in the garrison environment [34]. Patzkowski and colleagues reported that orthopedic conditions account for the greatest number of soldiers separated for medical reasons and that the additional burden accruing due to war is upwards of 10,000 personnel [6].

In a comprehensive investigation considering long-term disability within a cohort of combat-injured troops, Cross et al. documented that the average age of soldiers separated for medical reasons following war wounding was only 26.3 years [4]. Furthermore, 84% of soldiers, even those who did not sustain combat-related musculoskeletal trauma, were found to have one or more musculoskeletal conditions that failed to meet standards for continued military service [4, 22]. Degenerative arthritis, caused by traumatic injury in 75% or more of the cases considered [22], was the most frequent unfitting condition followed by loss of nerve function and posttraumatic stress disorder (PTSD) [4]. Three of the five unfitting conditions with the highest average disability were musculoskeletal in nature, as were six of the top 10 unfitting conditions as determined by impact (frequency $\times$ percent disability) [4].

The young age of these service members separated from military service, combined with the high degree of disability and overarching prevalence of behavioral health conditions, such as PTSD, may put such individuals at elevated risk of substance abuse, communicable disease, unemployment, and homelessness. For example, at an average of 3 years post injury, the Military Extremity Trauma Amputation/Limb Salvage (METALS) investigation found that less than half of the study's subjects were working or still on active duty [35]. Nearly 26% of the cohort were completely disabled, while 38% screened positive for depressive symptoms and a further 18% screened positive for PTSD [35].

Conclusions: Current State and Opportunities for the Future

In conclusion, musculoskeletal combat casualties during the wars in Iraq and Afghanistan have varied considerably from those of previous conflicts secondary to the development and routine use of IEDs by the enemy, the near universal use of individual and vehicular body armor, and the forward deployment of modern medical technologies and treatment algorithms [3, 10]. Explosive injuries have caused

over 75% of US combat casualties, accounting for the highest proportion in US military history [13]. The uniform use of individual body armor by US soldiers has minimized the impact of otherwise life-threatening injuries and has decreased the lethality of a gunshot wound to 4.6% compared to 33% in World War II [13]. Furthermore, the Mine-Resistant Ambush-Protected Vehicle (MRAP) has been successfully fielded by the US military to deal with the proliferating IED threat [2, 3]. Modern body armor and up-armored vehicles have greatly increased the protection of critical central body systems, while leaving the extremities relatively exposed to the blast-related effects that result in a large number of complex musculoskeletal injuries with heavy bacterial contamination and multiple concurrent injuries. The importance of appropriate treatment of combat-related musculoskeletal injuries cannot be overstated as 84% of all medical discharges from the military have at least one orthopedically related disqualifying condition [4].

During the past decade, the fundamental principles in the treatment of military musculoskeletal combat casualties have evolved and currently include the initial management of all open musculoskeletal combat wounds with patient stabilization and urgent debridement and irrigation of wounds, followed by provisional stabilization of fractures. Combat musculoskeletal wounds should initially be treated with a vacuum-assisted device, or left open, and generally require serial procedures to permit safe and durable closure or coverage [24, 36]. The definitive treatment of severe injuries most often occurs at high-volume, higher echelon facilities with greater technical resources.

Future research efforts and improvements in combat musculoskeletal wounds should include focus upon the incremental improvement in individual and vehicular body armor. Second, rigorous scientific studies should be conducted to evaluate the best methods of treatment of common, complex combat-related musculoskeletal injuries (e.g., combat-related grade IIIA and IIIB open tibial shaft fractures) by assessing both objective patient outcome scores and the service member's ability to return to duty or military service/work. Third, efforts should be directed at minimizing two of the most common complications of combat-related musculoskeletal injuries: infections [24, 32] and heterotopic ossification [25]. Infections can be devastating and frequent, developing in approximately 15–40% of injuries [24, 29, 32, 36]. Heterotopic ossification, the mature formation of lamellar bone in non-osseous tissue, occurs in approximately 63% of all major injuries to an extremity, including both salvaged limbs and amputations [25]. Fourth, the research should be focused on the treatment of posttraumatic degenerative arthritis to include articular cartilage restoration procedures and arthroplasty outcomes in young service members with high occupational demands since it is the most common disqualifying condition after a service member sustains a combat-related musculoskeletal injury.

Disclaimer Colonel Philip Belmat is an employee of the US Federal Government and the US Army. The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or reflecting the views of William Beaumont Army Medical Center, the Department of Defense, or US Government.

References

1. Schoenfeld AJ. The history of combat orthopaedic surgery. In: Owens BD, Belmont PJ Jr, editors. *Combat orthopaedic surgery: lessons learned in Iraq and Afghanistan*. Thorofare: SLACK Incorporated; 2011. p 3–12.
2. Blackburne LH 1831. US Army Med Dept J 2011;Apr–Jun:6–10.
3. Bosse TG. Advanced protection technology for ground combat vehicles. *J Am Acad Orthop Surg*. 2012;20(Suppl 1):S3–6.
4. Cross JD, Ficke JR, Hsu JR, Masini BD, Wenke JC. Battlefield orthopaedic injuries cause the majority of long-term disabilities. *J Am Acad Orthop Surg*. 2011;19(Suppl 1):S1–7.
5. Masini BD, Waterman SM, Wenke JC, et al. Resource utilization and disability outcome assessment of combat casualties from Operation Iraqi Freedom and Operation Enduring Freedom. *J Orthop Trauma*. 2009;23(4):261–6.
6. Patzkowski JC, Rivera JC, Ficke JR, Wenke JC. The changing face of disability in the US Army: the Operation Enduring Freedom and Operation Iraqi Freedom effect. *J Am Acad Orthop Surg*. 2012;20(Suppl 1):S23–30.
7. Icasualties.org. Iraq and Afghanistan coalition casualties. <http://icasualties.org>. Accessed 7 May 2013.
8. Belmont PJ Jr, McCrisky BJ, Sieg RN, et al. Combat wounds in Iraq and Afghanistan from 2005 to 2009. *J Trauma Acute Care Surg*. 2012;73(1):3–12.
9. Schoenfeld AJ, Newcomb RL, Pallis MP, et al. Characterization of spinal injuries sustained by American service members killed in Iraq and Afghanistan: a study of 2089 instances of spine trauma. *J Trauma Acute Care Surg*. 2013;74(4):1112–8.
10. Belmont PJ Jr, McCrisky BJ, Hsiao MS, et al. The nature and incidence of musculoskeletal combat wounds in Iraq and Afghanistan (2005–2009). *J Orthop Trauma*. 2013;27(5):e107–13.
11. Goodman GP, Schoenfeld AJ, Owens BD, et al. Non-emergent orthopaedic injuries sustained by soldiers in Operation Iraqi Freedom. *J Bone Joint Surg*. 2012;94(8):728–35.
12. Schoenfeld AJ. The combat experience of military surgical assets in Iraq and Afghanistan: a historical review. *Am J Surg*. 2012;204(3):377–83.
13. Belmont PJ Jr, Goodman GP, Zacchilli M, et al. Incidence and epidemiology of combat injuries sustained during “The Surge” portion of Operation Iraqi Freedom by a US Army Brigade Combat Team. *J Trauma*. 2010;68(1):204–10.
14. Belmont PJ Jr, Thomas D, Goodman GP, et al. Combat musculoskeletal wounds in a US Army Brigade Combat Team during Operation Iraqi Freedom. *J Trauma*. 2011;71(1):E1–E7.
15. Schoenfeld AJ, Goodman GP, Belmont PJ Jr. Characterization of combat-related spinal injuries sustained by a US Army Brigade Combat Team during Operation Iraqi Freedom. *Spine J*. 2012;12(9):771–6.
16. Blair JA, Patzkowski JC, Schoenfeld AJ, et al. Spinal column injuries among Americans in the global war on terrorism. *J Bone Joint Surg Am*. 2012;94(18):e1351–9.
17. Davis JM, Stinner DJ, Bailey JR, Aden JK, Hsu JR. Factors associated with mortality in combat-related pelvic fractures. *J Am Acad Orthop Surg*. 2012;20(Suppl 1):S7–12.
18. Owens BD, Kragh JF Jr, Macaitis J, et al. Characterization of extremity wounds in Operation Iraqi Freedom and Operation Enduring Freedom. *J Orthop Trauma*. 2007;21(4):254–7.
19. Schoenfeld AJ, Dunn JC, Bader JO, Belmont PJ Jr. The nature and extent of war injuries sustained by combat-specialty personnel killed and wounded in Afghanistan and Iraq (2003–2011). *J Trauma Acute Care Surg* 2013 (Accepted for publication April 22, 2013).
20. Stansbury LG, Lalliss SJ, Branstetter JG, Bagg MR, Holcomb JB. Amputations in US military personnel in the current conflicts in Afghanistan and Iraq. *J Orthop Trauma*. 2008;22(1):43–6.
21. Schoenfeld AJ, Lehman RA Jr, Hsu JR. Evaluation and management of combat-related spinal injuries: a review based on recent experiences. *Spine J*. 2012;12(9):817–23.

22. Rivera JC, Wenke JC, Buckwalter JA, Ficke JR, Johnson AE. Posttraumatic osteoarthritis cause by battlefield injuries: the primary source of disability in warriors. *J Am Acad Orthop Surg.* 2012;20(Suppl 1):S64–9.
23. Ficke JR, Eastridge BJ, Butler FK, et al. Dismounted complex blast injury report of the Army dismounted complex blast injury task force. *J Trauma Acute Care Surg.* 2012;73(Suppl 5):S520–34.
24. Murray CK, Obremskey WT, Hsu JR, et al. Prevention of infections associated with combat-related extremity injuries. *J Trauma.* 2011;71(Suppl 2):S235–57.
25. Potter BK, Burns TC, Lacap AP, Granville RR, Gajewski DA. Heterotopic ossification following traumatic and combat-related amputations. Prevalence, risk factors, and preliminary results of excision. *J Bone Joint Surg Am.* 2007;89(3):476–86.
26. Ramasamy A, Evans S, Kendrew JM, Cooper J. The open blast pelvis: the significant burden of management. *J Bone Joint Surg Br.* 2012;94(6):829–35.
27. Kang DG, Lehman RA Jr, Carragee EJ. Wartime spine injuries: understanding the improvised explosive device and biophysics of blast trauma. *Spine J.* 2012;12(9):849–57.
28. Ragel BT, Allred CD, Brevard S, Davis RT, Frank EH. Fractures of the thoracolumbar spine sustained by soldiers in vehicles attacked by improvised explosive devices. *Spine.* 2009;34(22):2400–5.
29. Lehman RA Jr, Paik H, Eckel TT, et al. Low lumbar burst fractures: a unique fracture mechanism sustained in our current overseas conflicts. *Spine J.* 2012;12(9):784–90.
30. Helgeson MD, Lehman RA Jr, Cooper P, et al. Retrospective review of lumbosacral dissociations in blast injuries. *Spine.* 2011;36(7):E469–75.
31. Penn-Barwell JG, Bennett PM, Powers D, Standley D. Isolated hand injuries on operational deployment: an examination of epidemiology and treatment strategy. *Mil Med.* 2011;176(12):1404–7.
32. Mody RM, Zapor M, Hartzell JD, et al. Infectious complications of damage control orthopaedics in war trauma. *J Trauma.* 2009;67(4):758–61.
33. Ramasamy A, Midwinter M, Mahoney P, Clasper J. Learning the lessons from conflict: pre-hospital cervical spine stabilization following ballistic neck trauma. *Injury.* 2009;40(12):1342–5.
34. Frank AJ. Orthopaedic injuries before combat deployment—will the soldiers be ready for combat when their unit is called upon? *Mil Med.* 2011;176:99:1015–8.
35. Doukas WC, Hayda RA, Frisch HM, et al. The Military Extremity Trauma Amputation/Limb Salvage (METALS) study: outcomes of amputation versus limb salvage following major lower-extremity trauma. *J Bone Joint Surg Am.* 2013;95(2):138–45.
36. Tintle SM, Keeling JJ, Forsberg JA, et al. Operative complications of combat-related trans-tibial amputations: a comparison of the classic Burgess and modified Ertl tibiofibular synostosis techniques. *J Bone Joint Surg Am.* 2011;93(11):1016–21.

Chapter 3

The Burden of Deployment-Related Non-battle Injuries (NBIs) and Their Impact on the Musculoskeletal System

Kenneth L. Cameron

List of Acronyms

BCT	Brigade Combat Team
DNBI	Disease and Non-battle Injury
FORECAS	Medical Casualty Forecasting System Software
NBI	Non-battle Injury
OIF	Operation Iraqi Freedom
OEF	Operation Enduring Freedom
ODS	Operation Desert Storm/Shield
TRAC ² ES	US Transportation Command's Regulating and Command and Control Evacuation System
TRANSCOM	US Transportation Command
WWI	World War I
WWII	World War II

Introduction

In the previous chapter, Schoenfeld and Belmont discuss the burden of traumatic combat-related injuries in the military and note that the majority of these injuries impact the musculoskeletal system. Despite the large volume of news reports focused on battle-related injuries resulting from the recent conflicts in Iraq and Afghanistan, these injuries are only the tip of the iceberg. Soldiers have traditionally been two to five times as likely to be hospitalized or medically evacuated from combat zones due to disease and non-battle injuries (DNBIs) than for injuries directly related to combat [1–9], and trends in the distribution of DNBIs have significantly shifted

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over the last century [3, 6, 10]. Understanding the factors associated with the distribution and impact of DNBIs is critical information for effective logistical planning and providing adequate medical support during combat operations [7]. Understanding the burden of DNBIs is also important in planning for the subsequent care that will be needed following deployment [11, 12]. The purpose of this chapter is to provide an overview of the burden that non-battle injuries (NBIs) pose during military operations and deployments. We will discuss historical trends in the distribution of NBIs and also review the most recent data on NBIs from the Gulf War and the conflicts in Iraq and Afghanistan. Finally, we will discuss the prevention of NBIs during military deployments.

The Historical Impact of Disease and Non-battle Injury

Historically, DNBIs in the military have resulted in more deaths during deployments when compared to injuries sustained in combat; however, when morbidity is examined in addition to mortality, it is clear that DNBIs result in far more combat ineffectiveness than casualties due to battle [13]. Holland and Long [4] reported that DNBIs during World War II (WWII) accounted for 82.8% of all lost duty days when compared to battle injuries. They also noted that the large majority of time loss was due to disease (82.7%) in comparison to NBIs (17.3%) when only lost duty days due to DNBIs were examined [4]. Though disease accounted for the majority of lost duty days, NBIs resulted in nearly four times as many deaths when compared to disease during WWII [4]. Nearly one third of these deaths were due to injuries sustained in motor vehicle accidents.

Rates of hospitalization for disease, NBIs, and battle injuries among US Army personnel during deployments from WWII through operations in Bosnia are presented in Fig. 3.1 [6]. These data suggest that hospitalizations during deployment that are due to disease have decreased substantially over time, while the proportion of hospitalizations for NBIs has increased. Similar results were observed when the distribution of casualties in the Navy and Marine Corps was examined from World War I (WWI) through the Vietnam conflict [3]. During WWI, sailors and marines were 16 times more likely to be admitted to the hospital for DNBIs than for battle wounds; however, admissions for traumatic injuries were only slightly higher when compared to prewar data. During WWII, sailors and marines were 88 times more likely to be hospitalized during deployment for DNBIs than for combat injuries, and admissions for NBIs increased 28% in comparison to prewar data. Similar results were observed during the Korean War with 84 admissions for DNBIs for every combat injury admission. Though the ratio of hospitalizations due to DNBIs compared to battle injuries fell to 17:1 during the Vietnam conflict, the lowest since WWI, for the first time acute traumatic injury emerged as the top reason for DNBI admission [3]. Among marines serving in Vietnam, NBIs were the leading cause of hospitalization with a rate of 116.9/1000 person-years, which was 2.5 times higher when compared to marines not serving in theater [7]. This was primarily attributed

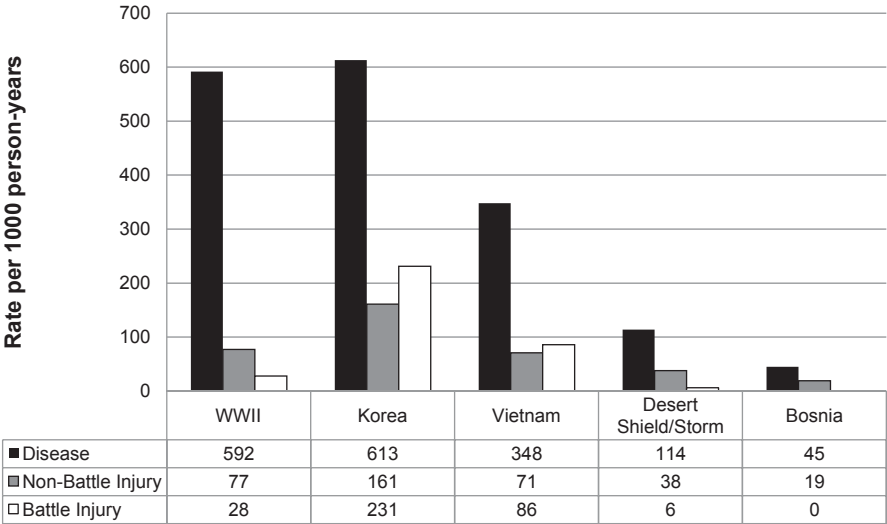


Fig. 3.1 US Army hospitalization rates for disease and non-battle injuries during deployment compared to battle injuries from World War II (*WWII*) through Bosnia. (Adapted from Jones et al. [6])

to an increase in combat wounds combined with a decrease in admissions due to disease [3].

While our ability to control and treat infectious diseases has led to substantial reductions in the number of troops that require hospitalization and medical evacuation during combat operations, the burden of NBI has remained relatively constant [3, 14]. Military service members were much more likely to be hospitalized for infectious diseases during deployment in the early half of the last century through the conflict in Vietnam [3, 6]; however, injuries and musculoskeletal conditions accounted for a much larger proportion of DNBI casualties during Operation Desert Shield/Storm (ODS), Operation Iraqi Freedom (OIF), and Operation Enduring Freedom (OEF) [2, 6, 14, 15]. Hauret et al. [2] reported that 83 % of medical evacuations from OIF and OEF were due to DNBIs and that 34.8 % of these were due to NBIs compared with 48.2 % that were due to disease. When only examining medical evacuations due to DNBIs, 58 % were due to disease while the remaining 42 % were due to NBIs, with the majority of these injuries impacting the musculoskeletal system.

Overall, these data suggest that DNBIs have historically impacted force readiness to a much larger degree than injuries sustained in combat and that DNBIs consistently account for 75–85 % of all hospitalizations and medical evacuations during military operations. This has remained relatively persistent since WWI. They also indicate that over 80 % of DNBIs were due to diseases in the early half of the last century when compared to NBIs; however, according to recent data, NBIs resulted in nearly half of all DNBIs medical evacuations during OEF and OIF and over half of all hospital admissions during ODS. As a result, a much larger proportion of

soldiers are being hospitalized and medically evacuated from deployment during contemporary military operations due to NBIs than has been reported in the past.

Non-battle Injuries During Contemporary Military Operations

In the previous section, we discussed the historical impact of DNBIs during military deployments and how trends related to the impact of disease and NBIs have shifted during recent military conflicts. During contemporary military operations, we have observed that musculoskeletal injuries and conditions have emerged as leading causes for hospitalization and medical evacuation due to DNBIs [2, 14, 15]. An increased emphasis on injury surveillance during and following recent military operations and deployments [12, 14] has resulted in a much clearer picture of the total burden that these NBIs place on military service members and the Military Health System and Veterans Administration as well as the impact they have on military readiness. This section will review the recent literature related to NBI, including data from ODS and other military and humanitarian operations through OIF and OEF.

Operation Desert Storm/Shield and Military Deployments in the Early 1990s

Writer et al. [14] reported on NBI casualties within the US Army during ODS and other military and humanitarian deployments during the early 1990s. Improved medical surveillance made these data available sooner than they had been during previous military operations; however, in the case of ODS they were still not available for analysis until 3 years following the operation. NBIs were the leading cause of death during ODS with 183 fatalities compared to only 147 due to combat injuries [14, 16]. This may have been due, in part, to the long buildup phase, and relatively short combat phase, during the first Gulf War. During ODS, NBIs and musculoskeletal injuries and conditions were the leading causes of hospitalization, accounting for 25 and 13 % of all hospitalizations, respectively. The most common types of NBIs treated during ODS were primarily acute orthopedic injuries, including fractures, sprains and strains, and joint dislocations among the top four types of injuries treated. The three most common causes of NBI hospitalization during ODS were motor vehicle accidents (4.0/1000 person-years), falls (4.0/1000 person-years), and sports and athletics (3.6/1000 person-years), which accounted for 56 % of all NBI hospitalizations [14]. The authors also reported that injury was also among the leading causes for hospitalization and outpatient visits during deployments to Somalia and Haiti and military exercises in Egypt, where 70 % of all cases

were sprains and strains with three quarters being acute injuries and the remaining one quarter being due to chronic conditions or aggravation of a prior injury [14]. Overall, NBIs primarily affecting the musculoskeletal system were a leading cause of both inpatient and outpatient visits during all of these operations.

Operations Enduring Freedom and Iraqi Freedom

In contrast to prior military operations, a number of publications documenting the impact of DNBIs during OIF and OEF across the various branches of military service have appeared in the literature [1, 2, 8–12, 15, 17–19]. Additional advances to injury and illness surveillance infrastructure [17, 18] as well as individual efforts by military medical providers have provided more robust data on DNBIs than have been available for previous military deployments. These data have also been available sooner, which has enabled early and ongoing assessments of the impact of NBIs during OIF and OEF. This has also been possible due to the long duration of sustained military operations in Iraq and Afghanistan compared to previous military engagements.

Several studies have examined the frequency and causes of NBIs significant enough to require medical evacuation from Iraq and Afghanistan [9–11, 15, 17, 19]. Most of these studies have relied on data from the US Transportation Command's (TRANSCOM) Regulating and Command and Control Evacuation System (TRAC²ES), which is used for tracking aeromedical evacuations from theater [17]. The TRAC²ES was developed as an administrative tool to track the movement of military service members requiring medical air evacuation [18]. The system integrates logistical and transportation information as well as clinical decision-support elements in support of the Department of Defense's medical transportation mission [17]. Data elements from TRAC²ES are now routinely provided for medical surveillance purposes to the Armed Forces Health Surveillance Center via the Assistant Secretary of Defense for Health Affairs, and these data are integrated with data from the Defense Medical Surveillance System [15, 17].

The potential utility of TRAC²ES for medical surveillance among troops deployed in support of OEF and OIF was initially described by Hauret et al. in 2004 [18]. Their preliminary analysis examined medical evacuation data from TRAC²ES for all military personnel that were evacuated from the US Central Command Area of Responsibility (OEF and OIF) between 1 January 2003 and 22 November 2003. The majority of service members medically evacuated during the study period were less than 30 years of age, were in the junior enlisted ranks (E1–E4), and were deployed in support of OIF. Furthermore, nearly half of all medical evacuations during the study period were due to injuries, and over 75 % of those injuries were classified as NBIs. Injuries and musculoskeletal conditions were the leading diagnoses requiring medical evacuation from theater during the study period, accounting for nearly 40 % of all evacuations. In a 10 % random sample ($n=954$), the ICD-9-CM codes and patient history text fields in TRAC²ES were reviewed to validate the data in the

system and determine causes of injury codes. Overall, there was a high degree of consistency between the data in TRAC²ES and the results from the random sample that was reviewed. Similar to data reported for ODS, the most common causes of NBIs during the study period were (1) falls, (2) motor vehicle accidents, (3) sports and physical training, (4) crushing and blunt trauma, and (5) lifting, pushing, and/or pulling.

A more detailed analysis of medical evacuation data from TRAC²ES among military service members deployed in support of OIF between 1 January 2003 and 31 December 2003, combined with data elements from the Defense Medical Surveillance System, was subsequently published [17]. The results of this study essentially confirmed and extended the preliminary findings reported by Hauret et al. [18]. Nearly 75% of all medical evacuations from OIF during 2003 occurred during the second and third quarters of the year [17]. The most common reason for medical evacuation was DNBI, which was responsible for 86.5% of all evacuations from OIF during the study period. Nearly all medical evacuations (94%) during the study period were classified as routine, suggesting that the patient could safely be evacuated within 72 h of their initial medical encounter [17]. The remaining medical evacuations were classified as priority (4.6%) requiring transportation with 24 h with minimal delays, or urgent (1.4%) requiring immediate transport to save life or limb or to prevent serious complications. The leading diagnoses requiring medical evacuation during the study period were injuries and musculoskeletal conditions (40.8%), similar to the findings reported by Hauret et al. [18]. In addition, orthopedic surgical care was the leading specialty care category required to treat the medical conditions of evacuees, when the need for specialty care was evaluated among those requiring medical evacuation from OIF during the study period.

Another study examined combat and DNBI casualties among US Army and marine corps personnel that were significant enough to require hospitalization during the Major Combat Phase, and the subsequent Support and Stability Phase, of OIF [9]. Similar to previous studies, the authors utilized medical evacuation and hospitalization data from TRAC²ES for the Major Combat Phase of OIF (March 21–April 30, 2003); however, they relied on data from the Joint Patient Tracking Application to document casualties during the subsequent Support and Stability Phase of OIF (March 1, 2004–April 30, 2005). While both systems are part of the Theater Medical Information Program-Joint, it is unclear whether data from these two administrative systems are comparable and equally effective for surveillance purposes. Regardless, the study reported some interesting findings. Notably, the phase of OIF was significantly associated with the type of casualties requiring hospitalization during the study period. Specifically, a significantly greater proportion of DNBI casualties were reported during the Support and Stability Phase of OIF (76.4%) when compared to the Major Combat Phase (63.4%). Overall, DNBI's accounted for 75% of all hospitalizations during both phases combined. As reported previously in other studies, the majority of casualties were males (90%) and serving in the Army (83.5%); however, those serving in the Marine Corps were more likely to sustain combat-related injuries. Among the DNBI's reported, injury and muscu-

loskeletal conditions were again reported as the leading reasons for hospitalization regardless of phase, and the distributions were similar among males and females.

In a series of follow-up studies [2, 3, 19] to their preliminary work [18], Hauret and colleagues examined the distribution and causes of NBIs significant enough to require medical evacuation from OEF and OIF. They conducted an analysis of medical evacuation data from TRAC²ES among military service members deployed in support of OIF between March 2003 and December 2006 and among service members deployed in support of OEF between October 2001 and December 2006 [2]. They also supplemented the air evacuation data with information obtained from accident investigations and casualty reports. Overall, they reported that 83% of medical evacuations from OIF and OEF during the study period were due to DNBIs and that 34.8% of these were due to NBIs compared with 48.2% that were due to disease. When only examining medical evacuations due to DNBIs, 58% were due to disease while the remaining 42% were due to NBIs, with the majority of these injuries impacting the musculoskeletal system. Similar to previous reports, over 90% of soldiers evacuated for NBIs were males, over half were less than 30 years of age, and most were in the junior-enlisted (OIF) and senior-enlisted (OEF) ranks. The top five diagnostic categories for injuries significant enough to require medical evacuation were (1) fractures, (2) inflammation and pain due to overuse, (3) joint dislocations, (4) sprains and strains, and (5) internal joint derangement [2]. Fractures, joint dislocations, and sprains and strains accounted for over 71% of all NBIs requiring medical evacuation from OIF and OEF. Notably, all of these diagnoses represent orthopedic injuries affecting the musculoskeletal system. The top five anatomic locations of NBIs significant enough to require medical evacuation from OIF or OEF included the low back and upper and lower extremities, specifically the (1) back, (2) knee, (3) wrist and hand, (4) foot and ankle, and (5) shoulder [2]. Overall, 75% of all NBIs requiring medical evacuation impacted the upper or lower extremities. Approximately 53% of all NBIs were documented as acute traumatic injuries, and 28% were classified as injury-related musculoskeletal conditions. By and large, more than 80% of all NBIs requiring medical evacuation from theater fell into these two major diagnostic subgroups. The four leading categories for cause of injury requiring medical evacuation for NBIs from OIF and OEF in rank order included: (1) sports and physical training, (2) falls and/or jumps, (3) motor-vehicle-related accidents, and (4) crushing or blunt trauma. It is noteworthy that sports and physical-training-related injuries were the leading causes of medical evacuation for NBIs from both Iraq and Afghanistan during the study period. A follow-up study reported that sports and physical-training-related injuries remained the leading cause of NBIs significant enough to require medical evacuation through 2011 in Iraq and 2012 in Afghanistan [19]. When sports and physical-training-related injuries were examined in this follow-up study, basketball (24%), physical training (19%), weightlifting (17%), and American football (16%) resulted in the highest proportion of injuries in this category. The most common types of sports-related NBIs requiring medical evacuation were sprains and strains (29%), fractures (22%), and joint dislocations (16%) [19]. Finally, the most commonly affected body parts were the knee (26%), ankle and foot (15%), hand and wrist (14%), and shoulder (14%)

[19]. Another follow-up study [1] reporting on medical evacuation data from Iraq between 2003 through 2011 confirmed and extended many of the findings initially reported by Hauret et al. [2].

Cohen et al. [10] examined medical evacuation data from OIF and OEF and factors associated with return to duty within 2 weeks between January 2004 and December 2007. The authors reviewed medical evacuation data contained in a database maintained by the Deployed Warrior Medical Management Center in Landstuhl, Germany. Similar to previous studies, approximately 75% of all medical evacuations were due to DNBIs. In each of the 4 years examined during the study period, NBIs affecting the musculoskeletal system were the leading causes for medical evacuation. Approximately 33% of those medically evacuated from OEF returned to their unit in Afghanistan within 2 weeks of evacuation, and only 21% of those medically evacuated from OIF returned to their unit within 2 weeks in Iraq [4]. The majority of those returning to duty were medically evacuated for DNBIs, with only 4% of those sustaining combat injuries returning to duty within 2 weeks. Musculoskeletal injuries and injury-related musculoskeletal conditions were among the leading diagnostic categories that prevented military service members with NBIs from returning to duty within 2 weeks of medical evacuation. Specifically, 87% of those with musculoskeletal injuries or conditions and 86% of those with back injuries or pain were unable to return to duty following medical evacuation for NBIs. Overall, military service members who were evacuated due to a NBI that affected the musculoskeletal system were 54% less likely to return to duty, and those evacuated with back injuries or pain were 59% less likely to return to duty within 2 weeks of evacuation in multivariable statistical models [10]. The authors noted that the most common NBIs requiring medical evacuation from theater were also the same injuries that were less likely to permit a service member to return to duty following evacuation (e.g., musculoskeletal injuries and conditions, back injuries, and pain). This noteworthy finding has important implications for injury prevention and force health protection among deployed troops.

Another group of authors examined DNBIs sustained by a single US Army Brigade Combat Team (BCT) during a 15 month deployment to Iraq in support of the counterinsurgency campaign during OIF known as “The Surge” [1]. They conducted a retrospective cohort study to identify all injuries and illnesses among the 4,122 deployed soldiers during the study period. In addition to examining fatalities and medical evacuations due to DNBIs, they also examined NBIs and illnesses that were treated in theater and returned to duty within 72 h of initial medical evaluation (Fig. 3.2). Similar to previous reports, 77.2% ($n=1324$) of all casualties during the deployment were due to DNBIs. Of the DNBI casualties sustained by the BCT during the study period, only 15.5% were significant enough to require medical evacuation from theater, with the majority (83.9%) being managed within theater and returned to duty within 72 h. Significantly higher rates of DNBIs were observed in female soldiers when compared to males, regardless of whether they were managed in theater and returned to duty or medically evacuated. Rates of DNBIs were also significantly higher in the enlisted ranks as reported previously in other studies. Again, musculoskeletal injuries represented the majority of all DNBI casualties

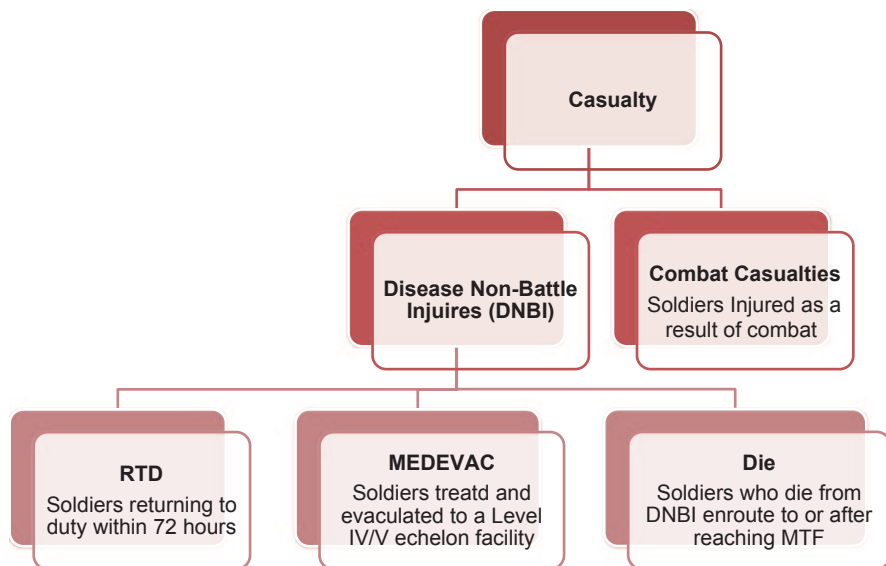


Fig. 3.2 Definitions and classification scheme of military casualties. *MTF* military treatment facility, *RTD* return to duty, *MEDEVAC* medical evacuation. (Adapted from Waterman et al. [8])

(50.4%) during the 15-month deployment; however, nearly all of these injuries (91.5%) were managed in theater and returned to duty within 72 h. While the majority of studies on NBIs have primarily been limited to injuries significant enough to require medical evacuation or cause fatality, this study provided unique insight into NBIs that were managed in theater and returned to duty; though a later report suggests that some of these injuries were significant [13]. Musculoskeletal injuries comprised the majority of all patients managed in theater (54.9%) and returned to duty. Musculoskeletal NBIs were almost evenly distributed between the lower extremity (42.6%) and the upper extremity (40.5%), with the remaining injuries affecting the axial spine (16.9%). The most common site of NBIs in rank order included the (1) hand (17.5%); (2) knee (13.5%), ankle (13.5%), and lumbar spine (13.5%); and (3) shoulder (11.8%). Though several studies suggest that DNBI make up 75–85% of all casualties significant enough to require medical evacuation; this study suggests that they also make up the majority of injuries and illnesses managed within theater and that musculoskeletal injuries account for the largest burden among these NBIs.

While the majority of studies have looked at NBIs during deployments within the US Army and US Marine Corps, Eaton et al. [12] recently examined NBI casualties among US Air Force personnel deployed in support of OEF and OIF. They examined NBIs documented among all Air Force personnel deployed to the Middle East between September 11, 2001 and October 31, 2006. They queried data on NBIs for all clinical visits at fixed medical facilities in the Middle East via the Global Expeditionary Medical System database. Similar to previous studies, they

also examined data in TRAC²ES for all NBIs significant enough to require medical evacuation during deployment. Musculoskeletal injuries including sprains and strains accounted for over half (53.0%) of all NBIs during the study period. As reported previously, incidence rates for NBIs were highest in the enlisted ranks and decreased with increasing military rank. Contrary to their original hypotheses, the authors reported that Guard and Reserve component airmen were less likely to experience NBIs when compared to those on active duty.

In a series of survey studies, Sanders and colleagues attempted to document the burden of DNBIs that was not significant enough to require medical evacuation from OEF and OIF [20, 21]. They reported that 34.7% of service members surveyed reported at least one NBI with the majority of these injuries affecting the musculoskeletal system [20]. They reported no differences in NBIs when injuries sustained by service members in Iraq and Afghanistan were compared, which is similar to the results reported by Hauret et al. [2]. The greatest single cause for NBIs reported was participation in sports and physical training, which is also consistent with the data reported by Hauret et al. [2] for injuries significant enough to require medical evacuation. In a follow-up survey, the authors extended their work related to NBIs [21]. They reported that 84.8% of those reporting NBIs obtained medical care for their injuries. Furthermore, 42.2% reported that their NBIs impacted job performance and 36% reported being placed on limited duty for an average of 6 days. Approximately 5% of the injuries reported were significant enough to require hospitalization in theater to manage the injury, and only 2.4% reported NBIs that were significant enough to require medical evacuation from theater but not significant enough to prevent the service member from eventually returning to duty. Again, sports and physical training and heavy lifting were the most common causes of the most severe NBIs reported [21].

As noted previously, Belmont et al. [1] reported that musculoskeletal injuries represented the majority of all DNBI casualties (50.4%) during the 15-month deployment among members of a US Army BCT; however, nearly all of these injuries (91.5%) were managed in theater and returned to duty within 72 h. Musculoskeletal injuries comprised the majority of all patients managed in theater (54.9%) and returned to duty. As a result, many of these non-emergent NBIs required definitive care upon return from deployment [13]. In a follow-up study, Goodman et al. [13] examined these non-emergent orthopedic injuries in the same BCT following deployment. Based on their observations, many soldiers returning from a full combat deployment presented with non-emergent musculoskeletal injuries and conditions that required medical care. These injuries may be disregarded as insignificant in the combat environment, may be ignored by soldiers wanting to stay with their unit and fellow soldiers, or may be identified as insufficient to warrant medical evacuation where service members are treated in theater and returned to duty [1, 12]. A total of 731 orthopedic consultations were conducted among the 3787 soldiers that completed the deployment without being medically evacuated. Nearly 90% of the injuries or conditions warranting consultation were the result of non-battle musculoskeletal injuries or exacerbation of a previous injury or condition during deployment. Of the soldiers ($n = 140$) returning from deployment, 4% required an

orthopedic surgical procedure as a result of their injury. While the authors were unable to systematically document the cause of injury among these service members, it is reasonable to assume that a large proportion of these injuries and conditions were likely due to sports participation and physical training based on the available epidemiological data [2, 19–21]. The surgical procedures were to treat internal derangement of the knee (e.g., meniscus tears, ACL rupture, articular cartilage lesions, etc.), shoulder instability (e.g., dislocations and subluxations), and superior labrum anterior to posterior (SLAP) lesions. These injuries included 19 first-time anterior or shoulder dislocations/subluxations and 18 anterior cruciate ligament ruptures. These data, combined with the observations reported by Sanders and colleagues [20, 21], suggest that even when NBIs are managed in theater, these injuries can have significant long-term impact on the health of military service members, can impact their ability to do their job during the remainder of their deployment, and can contribute to long-term morbidity after deployment affecting force readiness in the future.

Overall, these studies suggest that NBIs are a substantial problem during contemporary military operations and deployments, and these injuries significantly impact force readiness. Furthermore, these studies consistently demonstrate that the majority of NBIs affect the musculoskeletal system and primarily the lower and upper extremities. The top five anatomic locations of NBIs significant enough to require medical evacuation from OIF or OEF include the (1) back, (2) knee, (3) wrist and hand, (4) foot and ankle, and (5) shoulder [2]. Specifically, orthopedic injuries to the low back, fractures, sprains and strains, joint dislocations, and inflammation due to overuse are common among deployed service members. Musculoskeletal injuries are a leading cause of NBIs, whether these injuries are significant enough to require medical evacuation [2, 10, 18] or less significant where they can be managed within theater [1, 20, 21]; however, even musculoskeletal NBIs managed in theater may require additional definitive care and surgery following deployment [12]. While many musculoskeletal NBIs are significant enough to require medical evacuation during modern combat operations, over 90% of these injuries may be initially managed within theater and returned to duty within 72 h [1]. These data suggest that traditional military medical planning based on “inpatient beds” may be obsolete and insufficient to support the large burden of the outpatient mission during contemporary military deployments [5]. Military service members medically evacuated from OIF and OEF due to musculoskeletal NBIs are much less likely to return to duty in theater within 2 weeks of medical evacuation [10]. The most common causes of musculoskeletal NBIs include sports and physical training, falls and jumps, motor vehicle accidents, crushing or blunt trauma, and heavy lifting. Those serving in the Army and Marine Corps as well as those in the enlisted ranks are at the greatest risk for NBIs during deployment; however, those in the other services are still at substantial risk for NBIs during deployment.

Estimating the Burden and Resource Impact of Non-battle Injuries During Military Deployments

A critical component in planning for successful military operations is ensuring that adequate medical personnel, equipment, and supplies are available and positioned where needed to provide the medical care necessary to save lives and mitigate the impact of combat casualties and DNBIs during deployment.²⁴ Based on the data reviewed so far, the latter task of caring for DNBIs during deployments will likely require the majority of medical resources and have the greatest impact on the Military Health System and force readiness. Though several attempts have been made to project combat and DNBI casualties [22–25], projecting accurate estimates of injury patterns and medical resource needs have been challenging.

Blood and O'Donnel [22] utilized historical data on Marine Corps casualties from WWII, Korea, and Vietnam to develop a medical casualty forecasting system (FORECAS). The system was designed to estimate casualties during military operations based on several input variables including combat intensity (none, light, moderate, heavy, intense) type of casualty (battle injury, DNBI, or both combined), troop strength by category (infantry, combat support, and service support), region (Europe, East Asia, Southwest Asia), and duration of the operation in days (15, 30, 60, 90, 120). While the statistical models in FORECAS accurately depicted the statistical patterns in the empirical data on which the models were based, these models may have little relevance to modern combat operations, particularly in the Middle East and Persian Gulf regions. This is because the empirical data used to develop the models are limited to Marine Corps casualties, and combat operations and wounding patterns have significantly changed in recent conflicts (ODS, OEF, OIF) compared to previous military engagements (WWII, Korea, Vietnam) upon which FORECAS projections are based. As noted previously, these models may not account for the significant increase in musculoskeletal NBIs relative to disease observed in recent years. Finally, the casualty estimates derived from FORECAS are based primarily on hospital admissions data. As Belmont et al. [1] noted, many of the DNBI casualties during contemporary military deployments are treated in theater and returned to duty within 72 h. It is likely that the models based solely on hospital admissions do not account for the medical resources needed to care for these injuries during deployment.

Traditionally, models for estimating daily casualty incidence rates, including battle injuries and DNBIs, for resource planning purposes have relied on measures of central tendency such as average daily rates [24, 25]. Several limitations have been noted with this method, most notably among them is that using the average daily casualty incidence rates for estimating resource requirements can lead to critical shortfalls when casualty rates are above the mean [25]. As a result, percentile estimates and confidence intervals have been advocated as alternate approaches that may address these limitations in estimating casualty rates and resource requirements during military deployments [24, 25].

More recently, Wojcik et al. [24, 26] attempted to model DNBI rates based on hospital admissions data for US Army personnel deployed in support of ODS [24] and subsequently refined their model based on DNBI data from OEF and OIF [26]. In their initial models using data from ODS, they focused on percentile estimates as an alternative to the mean as recommended by Zouris and Blood [25], in addition to reporting average daily rates. This approach is helpful to planners as it provides a range of daily rates based on actual data. They also examined rates for three distinct phases of ODS including the buildup phase, the ground combat phase, and the post-combat phase. The DNBI rates for hospital admissions were comparable between the buildup and post-combat phases, but were substantially higher during the ground combat phase which only lasted for 4 days during ODS. The most commonly occurring diagnoses for all three phases were related to NBIs. Approximately 23 % of all admissions were due to NBIs during the buildup and post-combat phases; however, over 44 % of all admissions during the ground combat phase were due to NBIs. Musculoskeletal diseases and conditions were also a leading cause of NBI hospital admission during ODS. Combined, NBIs and musculoskeletal diseases and conditions accounted for approximately 37% of all DNBI hospital admissions during ODS. The authors concluded that the phase of each military operation is associated with the rate of admission for DNBI and recommended that separate rates associated with each phase should be used for future planning. They also recommended that the 95th percentile, rather than the average daily rate of admission for each phase of military operations, should be used during planning. Based on their data, planning using the average daily rate would have resulted in inadequate medical resources to meet the needs during 40 % of the days in theater, including all but one of the days during the ground combat phase. While these data are more relevant to contemporary military operations, the short ground combat phase during ODS may not be applicable to sustained military operations as observed in Iraq and Afghanistan.

To address this limitation and expand on their previous work, Wojcik et al. [26] incorporated data from OEF and OIF to refine and extend their DNBI model in a subsequent study. They examined data from the start of each operation through December 2004. Despite previous recommendations, the three separate phases (e.g., buildup, ground combat, post-combat stabilization) were only applied to OIF, as these distinct phases were not applicable to operations in Afghanistan during the study period. Overall, the authors noted that DNBI rates were comparable but lower during both OEF and OIF when compared to their previous data on ODS. While they attributed the observed reductions to improved force health protection efforts, data to suggest that any specific force health protection initiatives were responsible for the observed reductions were not provided. Furthermore, the DNBI models only included admissions data from the early years of both OEF and OIF. The authors noted this limitation and suggested that a complete analysis using complete data from both campaigns would be needed to support changes in policy and doctrine.

Similar to their previous study, NBI diagnoses were the leading cause for hospital admission due to DNBI during the follow-up study by Wojcik et al. [26] In a multivariable risk analysis for NBIs, the authors noted that demographic variables

including age, component (e.g., active, guard, reserve), military rank, gender, and unit type (e.g., combat, combat support, combat service support) were associated with the risk of NBIs. Regardless of whether they were serving in support of OEF or OIF, the risk of NBI was greatest in service members less than 20 years of age and decreased with increasing age. Reserve and National Guard component service members were 48 and 17%, respectively, more likely to be hospitalized for NBIs when compared to active duty service members deployed in support of OIF; however, there were no differences in the rate of admission by component in OEF. Those serving in the enlisted ranks were 82% more likely to be admitted for NBIs in Iraq and over four times more likely to be admitted for NBIs in Afghanistan. Females were 43% less likely to be admitted for NBIs in both OEF and OIF when compared to males. Finally, those serving in combat units were significantly more likely to be admitted for NBIs when compared to those serving in combat support or combat service support units, regardless of operation. These findings are consistent with the majority of studies that have looked at NBI rates and risk factors in recent years.

Combined, the studies reviewed in this section suggest that the military has made significant progress in understanding the burden of DNIBs and NBIs during deployments, and these data are being utilized to estimate medical resource needs with increasing accuracy. However, as noted by Wojcik et al. [26], a complete analysis of all data from OEF and OIF will be needed to further refine these models for sustained military operations across several years. Another limitation of these studies is that they do not account for NBIs that are seen and managed in theater. As noted previously, the vast majority of musculoskeletal NBIs experienced by deployed soldiers are managed in theater [1], despite the fact that many service members still require definitive care for these injuries following deployment [12]. Johnson et al. [5] noted that managing a large outpatient population is fundamentally different and more difficult in comparison to patients who are admitted for care due to differences in medical care needs and administrative tracking and processing requirements in a deployed setting. They also suggested that medical planning based solely on hospital admissions data, as has been the standard in the past, is “a relic from the Cold War” [5]. Further development of the models described in this section for medical planning should anticipate a large outpatient mission during future military deployments [5]. This will also require planners to incorporate data on the burden of outpatient care for NBIs in future models that estimate DNBI rates and medical resource needs.

Preventing Non-battle Injuries During Military Deployments

The available data consistently indicate that musculoskeletal-related NBI is a leading cause for soldiers seeking medical care in theater and for medical evacuations from theater. The data also suggest that participation in sports and physical training are a leading cause for these NBIs. Those serving in the Army and Marine Corps, as

well as younger soldiers and those in the junior and senior enlisted ranks, appear to be at the greatest risk for NBIs during deployment. Though many of these injuries are likely preventable, there is limited data available on the efficacy or effectiveness of injury prevention interventions among soldiers deployed in support of OIF or OEF.

While injury prevention during deployment is ultimately the responsibility of the unit commander, this duty may fall to the unit surgeon or medical officer. While most medical officers understand the importance of preventive medicine during deployments, many may lack formal training, may be uncertain how to practice it, or may have limited time and resources to focus on preventive efforts [27]. Even if they do have training in preventive medicine, they may lack expertise in evidence-based strategies to prevent sports and physical-training-related musculoskeletal injuries, which are the leading cause of medical evacuation from theater. Withers et al. [27] presented a preventive medicine framework that could be used during deployments to assist medical officers and support staff in organizing and coordinating prevention efforts. While NBI was included as a priority in this framework, specific strategies to prevent NBIs were lacking. Two of the top prevention priorities identified for the unit surgeon included (1) developing a preventive medicine plan and (2) obtaining command support for the plan. More recent work has described processes for identifying military injury prevention priorities [28] and presented a framework for building command support for injury prevention efforts in the military [29]. Furthermore, there have been significant advances in lower extremity injury prevention in the sports medicine literature in recent years; however, it is unclear if this information has been translated within military populations during deployments. While later chapters in this book will primarily focus on evidence-based injury prevention strategies, the need for preventing NBIs during military deployments cannot be overstated.

Conclusion

The significant burden of NBIs that impact the musculoskeletal system within military populations during deployment cannot be ignored. This is a critical public health problem within the military that negatively impacts force readiness. Several recent studies during OEF and OIF have provided a clearer picture of the factors that contribute to NBIs during deployment. Most of these studies have focused on NBIs significant enough to require medical evacuation from theater; however, the majority of the NBIs experienced during deployment may be treated in theater and returned to duty within 72 h. Regardless, many of those who are originally managed in theater will require definitive care and surgical intervention for their NBIs sustained during deployment upon returning from theater at the end of their deployment. While NBI has been recognized as a significant challenge, there is limited data to support the efficacy of force health protection interventions to mitigate the impact of NBIs during military deployments. Emerging strategies from the sports

medicine literature may play a role in preventing acute and chronic overuse NBIs during military deployments; however, data to confirm whether these findings can be translated to military populations during deployment will be needed.

Disclaimer The author is an employee of the US Federal Government and the Department of the Army. The opinions or assertions contained herein are the private views of the author(s) and are not to be construed as official or reflecting the views of Keller Army Hospital, the Army Medical Department (AMEDD), the Department of Defense, or US government.

References

1. Belmont PJ, Jr, Goodman GP, Waterman B, DeZee K, Burks R, Owens BD. Disease and nonbattle injuries sustained by a US Army Brigade Combat Team during operation Iraqi freedom. *Mil Med*. 2010;175(7):469–76.
2. Hauret KG, Taylor BJ, Clemmons NS, Block SR, Jones BH. Frequency and causes of non-battle injuries air evacuated from operations Iraqi freedom and enduring freedom, U.S. Army, 2001–2006. *Am J Prev Med*. 2010;38(Suppl 1):S94–107.
3. Hoeffler DF, Melton LJ, 3rd. Changes in the distribution of Navy and Marine Corps casualties from World War I through the Vietnam conflict. *Mil Med*. Nov 1981;146(11):776–779.
4. Holland BD, Long AP. Cost of non-battle injuries and diseases as compared to battle casualties. *Mil Med*. Jul 1955;117(1):46–50.
5. Johnson BA, Carmack D, Neary M, Tenuta J, Chen J. Operation Iraqi freedom: the Landstuhl regional medical center experience. *J Foot Ankle Surg*. 2005;44(3):177–183.
6. Jones BH, Perrotta DM, Canham-Chervak ML, Nee MA, Brundage JF. Injuries in the military: a review and commentary focused on prevention. *Am J Prev Med*. 2000;18(Suppl 3):71–84.
7. Palinkas LA, Coben P. Disease and non-battle injuries among U.S. Marines in Vietnam. *Mil Med*. 1988;153(3):150–155.
8. Waterman BR, Schoenfeld AJ, Holland CA, Goodman GP, Belmont PJ, Jr. Burden of musculoskeletal disease and nonbattle nontraumatic injury in both war and disaster zones. *J Surg Orthop Adv*. Spring 2011;20(1):23–29.
9. Zouris JM, Wade AL, Magno CP. Injury and illness casualty distributions among U.S. Army and Marine Corps personnel during Operation Iraqi freedom. *Mil Med*. 2008;173(3):247–252.
10. Cohen SP, Brown C, Kurihara C, Plunkett A, Nguyen C, Strassels SA. Diagnoses and factors associated with medical evacuation and return to duty for service members participating in Operation Iraqi Freedom or Operation Enduring Freedom: a prospective cohort study. *Lancet*. 2010;375(9711):301–09.
11. Eaton M, Marshall SW, Fujimoto S, Gould PL, Poole C, Richardson DB. Review of non-battle injuries in air force personnel deployed in support of Operation Enduring Freedom and Operation Enduring Freedom. *Mil Med*. 2011;176(9):1007–14.
12. Goodman GP, Schoenfeld AJ, Owens BD, Dutton JR, Burks R, Belmont PJ. Non-emergent orthopedic injuries sustained by soldiers in operation Iraqi freedom. *J Bone Joint Surg Am*. 2012;94(8):728–35.
13. Withers BG, Craig SC. The historical impact of preventive medicine in war. In: Kelley PW, editor. *Textbook of military medicine: military preventive medicine, mobilization, and deployment*. Vol 1. Washington, D.C.: Office of the Surgeon General at TMM Publications; 2003:21–57.
14. Writer JV, DeFraitres RF, Keep LW. Non-battle injury casualties during the Persian Gulf War and other deployments. *Am J Prev Med*. Apr 2000;18(Suppl 3):64–70.

15. Armed Forces Health Surveillance Center. Medical evacuations from operation Iraqi freedom/operation new dawn, active and reserve components, U.S. Armed Forces, 2003–2011. (MSMR). 2012;17(2):18–22.
16. Writer JV, DeFraités RF, Brundage JF. Comparative mortality among US military personnel in the Persian Gulf region and worldwide during operations desert shield and desert storm. *JAMA*. 1996;275(2):118–121.
17. Harman DR, Hooper TI, Gackstetter GD. Aeromedical evacuations from operation Iraqi freedom: a descriptive study. *Mil Med*. 2005;170(6):521–27.
18. Hauret KG, Jones BH, Canham-Chervak M, Bullock SH, Canada S, Knapik JJ. Frequencies and characteristics of medical evacuations of soldiers by air (with emphasis on non-battle injuries), operations enduring freedom/Iraqi freedom (OEF/OIF). *Medical Surveillance Monthly Report (MSMR)*. 2004;10(3):8–12.
19. Hauret KG, Taylor BJ, Patel A, Kersellius G, Comer J, Jones BH. Sports injuries among US Army soldiers deployed to operations Iraqi freedom, New Dawn, and enduring freedom, 2001–2012. Paper presented at: Third International Congress on Soldiers' Physical Performance; 18–21 August, 2014; Boston, MA.
20. Sanders JW, Putnam SD, Frankart C, et al. Impact of illness and non-combat injury during operations Iraqi freedom and enduring freedom (Afghanistan). *Am J Trop Med Hyg*. 2005;73(4):713–719.
21. Skeehan CD, Tribble DR, Sanders JW, Putnam SD, Armstrong AW, Riddle MS. Nonbattle injury among deployed troops: an epidemiologic study. *Mil Med*. 2009;174(12):1256–1262.
22. Blood CG, O'Donnell ER. A system to project injury and illness incidence during military operations. *J Med Syst*. 1995;19(6):457–64.
23. Lynch LC, Elliott CW, McMurphy P. Disease and nonbattle injury forecasting. *US Army Med Dep J*. 1999;Jul-Sep(3):2–8.
24. Wojcik BE, Hassell LH, Humphrey RJ, Davis JM, Oakley CJ, Stein CR. A disease and non-battle injury model based on Persian Gulf War admission rates. *Am J Ind Med*. 2004;45(6):549–557.
25. Zouris JM, Blood CG. Medical resource planning for combat operations: utilizing percentile estimates as an alternative to the mean. *J Med Syst*. 2000;24(6):379–387.
26. Wojcik BE, Humphrey RJ, Czejdó B, Hassell LH. U.S. Army disease and nonbattle injury model, refined in Afghanistan and Iraq. *Mil Med*. 2008;173(9):825–835.
27. Withers BG, Erickson RL, Petrucci BP, Hanson RK, Kadlec RP. Preventing disease and non-battle injury in deployed units. *Mil Med*. 1994;159(1):39–43.
28. Ruscio BA, Jones BH, Bullock SH, et al. A process to identify military injury prevention priorities based on injury type and limited duty days. *Am J Prev Med*. 2010;38(Suppl 1):S19–33.
29. Padua DA, Frank B, Donaldson A, et al. Seven steps for developing and implementing a preventive training program: lessons learned from JUMP-ACL and beyond. *Clin Sports Med*. 2014;33(4):615–632.

Chapter 4

Sports and Exercise-Related Injuries in the Military

Michael Garrison, Scott Dembowski, and Nathan Shepard

Introduction

Sports participation is a common method for military members to sustain and enhance physical fitness. The Army and Navy service academies entered intercollegiate sports competition in the late 1800s with a limited number of participants. After the Spanish-American War in 1898, the entire military began to embrace sports for soldier entertainment, enhanced morale, and improved fitness [1]. As time progressed, the role of sports participation moved from unorganized games to military-sponsored sports programs. While the benefits of sports participation are well known in terms of fitness and morale, the negative impacts in terms of injury and reduced readiness require further attention.

American military service members are required to perform a variety of tasks in the most difficult conditions imaginable. While technological advances have changed the manner in which war is conducted, the strength and stamina of individuals continue to be the foundation of American military power. Mental and physical toughness are requisite traits in the profession of arms, and sports participation and physical training are important tools in developing these traits. Douglas McArthur famously stated that “upon the fields of friendly strife are sown the seeds that, upon other fields, on other days, will bear the fruits of victory.” As a result, formal physical training programs integrating competitive and recreational sports are commonplace within the military to maintain the physical and mental aspects of readiness. While these physical activities can enhance readiness through fitness,

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camaraderie, and esprit de corps, they also predispose participants to the risk of musculoskeletal injury. Just as weapon systems are constantly being developed, issues that affect personnel readiness also continue to evolve and deserve further attention and research.

Hemorrhage from extremity injuries remains a leading cause of combat death [2]. As a direct result, military combat casualty care is heavily focused on controlling hemorrhage from vascular injury. This training coupled with the forward positioning of surgical teams, improvements in body armor, and advanced aeromedical evacuation have resulted in the lowest ratio of injured to killed service members in the history of warfare [3]. While these advancements in combat casualty care are remarkable, nonoccupational injuries exist as a more insidious medical concern that is degrading military readiness [4]. While unintentional musculoskeletal injuries do not normally affect life and limb, these injuries do result in lost duty time that strains the personnel readiness of military units and the military medical system [5]. Recent surveillance studies indicate that preventable non-battle injuries involving sports and physical training are the leading cause of medical evacuation from Iraq and Afghanistan [6].

Sports and fitness-related injuries are the leading cause of outpatient medical visits in the US military [7, 8]. When considering all aspects of medical complaints, unintentional injury results in the greatest negative impact on military readiness [9]. While military service members and civilian athletes require enhanced levels of physical fitness for job performance, maintaining that fitness requires participation in activities that can potentially lead to injury. In this chapter, we will discuss the epidemiology of sports and fitness injuries in the military, report on proven methods to reduce injuries, and highlight emerging trends in fitness development that will undoubtedly impact medical readiness in the future.

Sports Injury Surveillance and Epidemiology in the Military

Military studies conducted from training schools, individual units, and service-wide populations clearly demonstrate that musculoskeletal injuries resulting from physical training are a leading cause of outpatient medical visits [9–12]. While sports participation outside of mandatory physical training is not required, there are many opportunities, both formal and informal, for military members to participate. In the early 1900s, the Army Morale, Welfare and Recreation (MWR) division was established to build, operate, and maintain gyms and other fitness facilities on military installations. Since then, the MWR and similar organizations have continued to develop and improve sports and fitness opportunities for troops at home and while deployed. Most military installations have gymnasiums, courts, and fields for a wide variety of sports participation. Most installations have voluntary unit intramural sports leagues including flag football, basketball, soccer, volleyball, and soft-

ball. The intramural league is a friendly installation-wide program open to military members and their spouses. In addition to these outside voluntary leagues, sports activities are also routinely incorporated into mandatory unit fitness training.

The Armed Forces Sports (AFS) program is another opportunity provided for military members to train and compete in the highest levels of sports competition. This program was officially established in 1948 and paved the way for military personnel to have the opportunity to train and compete for national, Olympic, and international competitions, such as the International Military Sports Council (CISM) World Military Championships. “The AFS program offers 25 men and women team and individual sports; annually conducts 16 Armed Forces Sports Championships and 9 qualifying events/trial camps; participates in 9 U.S. national championships and 16 CISM Military World Championships. In 2012, 21 military service members participated in the London Olympic Games. The selection of the US delegation for national and international events occurs at the annual Armed Forces Championship or through a qualification process such as a trial camp” [13].

The army soldier athletics program, introduced in May 2013, is separate from the intramural leagues and pits battalions against one another in a semiannual competition. The goal is to increase the level of competition with a soldier-only program to recognize the best soldier-athletes. The events include men’s and women’s basketball, volleyball, soccer, flag football, softball, and cross-county along with coed combative teams. The battalion teams compete for installation level championships and the winners continue on to regional tournaments and conclude at the Chief of Staff of the Army Sports Championships. “The Army Sports Program embodies key elements of comprehensive soldier fitness—building physical fitness, strengthening resilience, fostering teamwork and camaraderie—while ultimately offering soldiers positive activity choices during discretionary times, thereby reducing soldier opportunities to engage in high-risk opportunities,” read the operations order signed by Lt. Gen. Mike Ferriter, commander of Installation Management Command [14].

The heavy emphasis on sports participation can lead to many positive effects such as increased morale, camaraderie, and fitness, but there is also a negative side. As mentioned earlier, sports and physical training injuries are a major reason for medical evacuation [6]. Many other studies also highlight the impact of injury during sports participation in a military population. In 2010, Burnham et al. analyzed injuries from basketball, flag football, and softball reported to the US Air Force (USAF) safety center between 1993 and 2002 [15–17]. They reported basketball as the sport causing most injuries during the 10 year study period. Interestingly, they also noted that basketball is the most popular sport in the USAF. Injuries related to basketball participation ranked 4th overall for total workdays lost, which included injuries not related to sports participation. The most common mechanism of injury was landing awkwardly from a jump (26%) followed by landing on another player’s foot (17%). Softball was the sport with the second most injuries that led to a lost workday and 5th overall on the list. The most common mechanism of injury was sliding (23%) followed by being hit by a ball (20%). Flag football was the sport with the third most injuries and 8th overall on the list with the most common

mechanism being contact with another player (42 %) followed by falling while running (14 %).

In agreement with these findings, softball, basketball, and football were the sports with the largest number of injuries in other military studies as well [7, 11]. Burnham et al. [15–17] also discussed potential ways to prevent or reduce injuries in these sports. These prevention strategies include training to improve balance, using ankle braces, implementing and enforcing rules, performing appropriate warm up and preseason conditioning, along with utilizing more safety equipment (helmets, eye and mouth guards, etc). Research demonstrates that training can improve jump-landing mechanics associated with knee anterior cruciate ligament (ACL) injury, which potentially leads to decreased risk of ACL tear during sports participation [18]. Monetary cost and time seem to be the main barriers to implementation of these prevention strategies. Although making sports participation safer can be more expensive in the short-term, these strategies are arguably cheaper in the long run if they reduce the number of workdays lost or result in fewer medical evacuations during military deployments.

The financial impact of sports injuries can range from lost training days to surgery and subsequent rehabilitation if serious enough. Some sports-related injuries may also lead to disability discharge and impact long-term health-related quality of life. It is estimated that approximately \$2 billion per year are spent on managing injuries to the ACL of the knee alone [19]. Considering that over 70 % of ACL injuries are of the noncontact variety, it seems that many of these may be preventable [19]. A 6-year study looking at hospitalizations due to sports injuries in the Army showed that they accounted for 29,435 lost work days each year with a rate of 38 and 18 per 10,000 for men and women respectively [7]. The knee was by far the most frequently injured body part with fractures being the most common injury. The knee is the most common body part injured in modern day sports; as many as 40 % of sports injuries are knee injuries [16, 20]. Knowledge of injury patterns common for each sport, and risk factors common to sports participants can allow medical personnel and team leaders to apply interventions to diminish the injury risk.

Military athletes are routinely involved in a variety of sports dependent on personal interest, season, facilities, and training calendar. There are risk factors specific to each sport that play a role in injury development. These extrinsic risk factors can be identified ahead of participation and in many cases mitigated to reduce injury risk. In addition to the sport itself, the athlete can also possess certain intrinsic risk factors that predispose them to injury. While intrinsic factors cannot be changed, they can be identified and taken into account when counseling athletes on sports participation. Examining intrinsic and extrinsic injury risk factors for specific sports, and athletes in general, can help identify areas that are amenable to change with appropriate injury-reduction programs.

Factors Associated with Musculoskeletal Injury During Sports Participation in the Military

Risk factors for sports injuries in the military and civilian populations are quite similar, as sports themselves have inherent risks that contribute to their injury patterns. There are several published studies identifying risk factors [20–26] and incidence rates [20, 21, 23–25, 27–29] of injury during sports and exercise participation in the military. In the civilian setting, there are similar reports on injury patterns, risk factors, and incidence rates in the literature [30]. Regardless of whether a risk factor is intrinsic or extrinsic, whether a risk factor is modifiable or not may be more important in developing and implementing potential injury prevention practices [31]. In the coming sections, we will compare the extrinsic and intrinsic risk factors for injury in civilian sports settings to military sports settings. Throughout the course of this discussion we will focus on conceptualizing these risk factors and the clinical relevance of this classification for sports and exercise-related injury prevention [31].

Extrinsic Risk Factors

Extrinsic risk factors for injury during sports participation are not inherent to the individual participant. Extrinsic factors that are specific to military units and military occupations can be more difficult to comprehend. Reducing these extrinsic risk factors is a relatively simple process in theory, but in practice there are many unique military obstacles to implementation. Equipment, playing surface, coaching, and rules enforcement are known extrinsic factors associated with sports injury [30]. In a military setting, mitigating these risk factors can be difficult as sports and physical training are often secondary concerns behind mission-specific training.

Military units vary from location to location by the type of unit, operational tempo, and training cycle. There may be a time during the year when a military unit is training at a high operational pace in preparation for an upcoming deployment, prolonged field training exercise (FTX), or skills validation assessment. Some unit leaders believe that offering a sports activity during physical training can be a way to reward soldiers for their hard work and give them a break from the normal rigors of physical training. This practice is also common when a unit returns from a deployment or long field training exercise. While commanders may feel that unit sports participation is a reward for a job well done, the risk of injury is higher due to lower levels of conditioning and fitness. The unit operational tempo is a modifiable extrinsic risk factor for sports injury. Commanders must be aware of this risk and produce a physical training plan accordingly. Furthermore, taking steps to ensure that known risk factors are accounted for when adding sports to the training calendar is critical in mitigating these risks.

Another extrinsic risk factor for sports injury is the use of appropriate safety equipment. In collegiate and professional athletics, it is mandatory for safety equipment to be utilized. For instance, in American football it is unheard of for a player to participate without a helmet or shoulder pads [32]. During military training, a soldier would never conduct a mission without appropriate protective equipment including a ballistic vest, helmet, or weapon. However, when these same soldiers participate in an organized game of flag football, they often wear their normal running shoes. Not wearing appropriate footwear greatly increases the risk of slipping and twisting injuries. The same footwear issue is present when military members participate in other sports as well. Wearing running shoes while playing basketball or softball can also lead to lower extremity injury. Running is perhaps the most popular military sport, and multiple studies indicate that appropriate footwear can help reduce injury. In the basic training environment, running injuries have been investigated in multiple settings with inappropriate footwear being cited as a significant contributing factor [33, 34].

The playing surface is another extrinsic modifiable risk factor for injury in the military setting. Typically, military sports are played in any available open space. These include grassy areas never designed or inspected for organizational sports use, and even large areas of concrete such as empty parking lots. Flag football participation by military personnel results in a considerable injury rate [16]. A major factor in many of these injuries revolves around the playing surface. Often times, open areas on military installations serve multiple purposes, are not level, and are filled with tire ruts and other obstacles that are not easily seen. Combining a poor playing surface with inappropriate equipment only increases the risk of injury. Commanders and unit leaders should take appropriate steps to ensure that appropriate facilities are available for organized sports activities that are added to the training calendar. Furthermore, unit leaders should ensure that the facilities are inspected for potential hazards prior to engaging in sports activities, and any noted deficiencies should be addressed to reduce injury risk.

In addition to equipment and playing surface, the lack of appropriate officiating and coaching are also risk factors for injury. It is common practice for military units to play a particular sport during unit physical training without a trained official. Military units also lack trained coaches or conditioning staff to ensure that members are prepared for sport participation. If the sport is conducted as part of a daily physical training program, there may be no officials or coaches and the responsibility lies with the participants to control the game. With this, it is fairly common for games to become increasingly competitive and physical. This style of play, that is often void of fundamentals and performed by unconditioned participants, creates an environment of increased injury risk. Planning sports activities where the rules of engagement are clarified prior to participation, and assigning personnel to monitor the rules during play, are relatively simple steps that can be taken by unit leaders to enhance the safety of these activities and reduce injury risk.

Intrinsic Factors

Intrinsic risk factors are those that are particular to the individual athlete. In some instances these factors may be modifiable; regardless, intrinsic risk factors require identification and subsequent mitigation if appropriate. Hamstring injuries are very common among sports participants and the risk factors for hamstring injury are widely published [35, 36]. Among the intrinsic risk factors, some of the most widely reported are age, flexibility, strength, fitness, and past history of injury [35, 36]. These intrinsic risk factors exist for military members participating in sports and physical training as well.

The first factor to consider is the overall fitness level of the sports participant. One might assume that a high level of fitness is required to join and remain in the military. While there are fitness requirements for military service, these requirements vary from service to service and the enforcement of these standards can vary from unit to unit. As a result, there are individuals in the military that do not meet height/weight or basic fitness standards. Military research indicates that current fitness levels can be a significant risk factor for future injury during military training [23–25]. Increasing the fitness level of military recruits prior to entry into their initial training can reduce the rate of musculoskeletal injury [29, 37]. Identifying members that possess an inadequate level of aerobic fitness and enforcing standards in place concerning passing fitness tests can also ensure that poor fitness becomes less of an impact on injury in the military. A factor often associated with low levels of aerobic fitness is obesity which can also increase the risk of injury [28, 38].

Obesity is another intrinsic risk factor for military and civilian athletes alike [30]. While there are height and weight standards across the military, the enforcement of these standards often varies from unit to unit. Fitness levels and obesity are both modifiable risk factors that are constantly measured as part of the normal unit physical training plan [28]. Identifying these individuals and implementing a plan for improvement prior to unit sports participation is vital to preventing musculoskeletal injury. Another easily identifiable risk factor for injury is history of previous injury.

History of a prior musculoskeletal injury is one of the major predisposing non-modifiable risk factors for injury development [39, 40]. While there is no consensus answer as to why this risk factor exists, one theory is that athletes return to sports prior to fully recovering from their previous injury [40–45]. Athletes or military members with a history of prior injury can be assessed by the sports medical staff to determine any rehabilitative needs prior to sports participation. In the military setting, recovery from injury is often focused on being cleared to participate in unit physical training and complete the mandatory physical fitness tests. These fitness tests are not sports-specific, so significant strength, mobility, or motor control deficits can still exist despite being cleared for full participation in military physical training. While past history of injury is not a modifiable risk factor, the intrinsic deficits that remain after injury may be modifiable, if identified. Furthermore, secondary prevention becomes much more important in military service members with a history of musculoskeletal injury.

Age is another intrinsic risk factor for sports injury development [46, 47]. While the youngest members of the military can be of a similar age to many civilian college athletes, the more experienced members of the military often approaches 45–50 years of age. Increasing years of experience are often associated with promotion and career advancement. Not surprisingly, a higher enlisted rank is found to correlate with increased injury during deployment [48]. Age may also be associated with the type of sports-related injuries experienced by military service members. A recent review reported that acute traumatic joint injuries and fractures seem to be more common in younger military service members, and the risk of these injuries decreases with increasing age. Conversely, the risk for chronic overuse injuries, injuries to the fibrocartilage in the knee and shoulder, and degenerative joint disease and osteoarthritis (OA) is lowest in younger age groups and increases with increasing age [49]. While age is not a modifiable risk factor for injury, it is an easily identifiable risk factor. Unit leaders must decide if the benefits of sports participation are worth the increased risk of injury for their more seasoned military members.

The final intrinsic risk factors to be discussed here include strength, flexibility, and neuromuscular control [50]. Arguably the most important aspect of physical training is the warm-up and cool-down periods. In the military setting, these are often neglected due to time constraints. Strength training in the military is often left to the individual members. Group strength training is rarely performed. When strength training is integrated into a fitness plan, the focus is on fitness test performance and not sports-specific skills. The concept of neuromuscular control has received considerable attention in the civilian sports medicine research literature. Not only is neuromuscular control a known risk factor for injury, integrating an intervention program to improve neuromuscular control can reduce injury risk specifically in the knee [51]. As noted previously, the knee is one of the most common sites for sports-related injury among military service members.

With all of the risk factors for injury discussed, the largest contributor to injury in the military population may be inadequate planning and execution, which can clearly be modified with appropriate command interest and support. A published physical training plan can ensure that participants arrive in the appropriate footwear. Inspecting the playing area prior to the day of competition can identify environmental risks for injury. Ensuring that all participants know the rules of engagement prior to participating in sports activities and that someone is designated to ensure these rules are followed to mitigate injury risk are all important strategies that can make sports participation safer in military populations. Appropriate planning can also help reduce the role that fatigue plays in injury production [23]. There are several studies looking at professional sports teams that identify fatigue as a significant intrinsic risk factor for various injuries [52–56]. Understanding the role of fatigue in a military setting may be best illustrated with an example. A service member on deployment may conduct daily patrols for 12–18 h per day carrying equipment that may exceed 85 pounds. In addition to the physical stresses associated with these missions, there are also significant mental stressors that can lead to fatigue and lack of focus. Upon return to their base, these military members may engage in a sporting activity to help recovery mentally from these stressful missions. Participating in

a disorganized sports activity, while physically and mentally fatigued, can increase the risk of musculoskeletal injury.

The majority of research studies focusing on sports injury prevention and management involve civilian athletes at the collegiate and professional levels. Military health-care providers specializing in the delivery of sports medicine, including physical therapists, orthopedists, and sports-trained physicians routinely integrate these research findings into the evaluation and management of injured soldiers. Advancements in the care of civilian athletic populations can have direct implications in the management of military athletes. Looking at the spectrum of care provided to civilian athletes, and comparing that level of care to that provided to military athletes might offer some insight into the management of military sports and fitness injuries.

In 2003, a collegiate football player competing for a nationally ranked university created a national controversy when responding to a question regarding his aggressive style of play. While his language was a bit more colorful than described here, the essence of his response included references to protecting yourself from other players attempting to harm you, competing in a war, and being a soldier on the playing field. His comments came at a time when American military members were involved in actual combat operations in both Afghanistan and Iraq. His realization that college athletics are not combat operations, along with words of advice from the university leadership, resulted in an immediate apology. This was not the first or last reference credited to athletes at all levels of competition alluding to battles occurring on the playing field. We provide care for civilian athletes in a manner consistent with their required level of performance when they step onto these proverbial battlefields. How can we provide that same level of care to military members whose ultimate performance is judged on actual battlefields? Perhaps the answer lies in integrating a civilian model of sports care for our military members [49].

Civilian athletes are afforded structured training programs specific for their sport, top notch training facilities, and readily available access to high quality sports medicine assets that are typically co-located in the training environment. Military service members are constantly preparing for situations where much more is at stake than a simple win or loss. The high rate of sports and fitness injuries prevalent in the military indicates a need to alter the model of health care provided to our military athletes [57]. While personnel and training issues represent seemingly insurmountable obstacles to implementation, integrating aspects of sports care proven effective in the civilian community can only help to improve upon musculoskeletal injury rates observed in the military environment.

One major difference between civilian and military sports participation management involves the planning phase of competition. Civilian institutions are proactive in the management of their athletes, fully aware that the development of injuries will lead to time away from sports participation. As a result, rules are in place that limit practice participation until conditioning is improved and a thorough pre-participation screening is conducted. Game participation is restricted until a minimum number of practices are completed. Appropriately trained medical personnel are involved in the development of conditioning plans, training schedules, and practice

flow. Practice and training intensities are gradually increased so that an athlete's performance level peaks at the time of competition. This progressive approach relies on athletes being able to fully participate in training sessions. Identifying those at risk for injury, prior to the start of conditioning, is thus paramount to success.

As previously mentioned, a thorough pre-participation screen is conducted on all civilian athletes prior to sports participation. Part of this screening includes the identification of risk factors for injury development. One of the major predisposing non-modifiable risk factors for injury development is history of a prior injury [39, 40]. Athletes with a history of prior injury can be further assessed by the medical staff to determine any rehabilitative needs prior to sports participation. Various screening tools can be used to identify athletes at a greater risk of injury. One such tool, the functional movement screen (FMS), identifies dysfunctional movement patterns. Athletes scoring low on this screening exam can then be further examined by a health-care professional to determine appropriate corrective exercises to be performed prior to athletic participation. A growing body of research suggests an elevated risk of injury with a lower score on this screening examination [50, 58–60]. Multiple studies also demonstrate that the FMS can be reliably performed by appropriately trained personnel [61–63]. The growing body of evidence demonstrates the validity of the FMS, that it might be applicable to large military populations. In addition to screening athletes prior to athletic participation, playing surfaces and equipment can also be analyzed to remove extrinsic risk factors for injury.

In a civilian setting, fields and sports equipment are thoroughly inspected prior to any type of sports participation. Research demonstrates that noncontact injuries of the lower extremities can be related to the type of playing surface [64]. As a result, third generation turf surfaces are routinely installed for collegiate and professional sport complexes [65]. Civilian studies are routinely published reporting on the injury rates observed with participation in different sports on different playing surfaces [66]. This research allows for the development of shoe recommendations for each sport and surface to produce the ideal footwear to playing surface relationship that minimizes injury production. Elimination of hazards, relating to field conditions or equipment deficiencies, is routinely accomplished prior to athletes stepping onto the field of competition. In the military setting, the condition of sports fields and training facilities can vary greatly depending on location. Several installations in the USA feature the latest generation artificial playing surfaces or well-maintained natural grass surfaces. Sports fields established at smaller installations or in deployed locations are often not as well-maintained and can pose a significant injury hazard for military athletes. Systematically employing fairly simple risk management strategies such as site inspections prior to activity could significantly reduce these hazards.

In contrast to typical organized sporting activities, the military model for sports participation tends to be far less organized in both the planning and execution stages. Some individuals train independently to accomplish personal fitness goals and others participate in a variety of intramural-type sports. Often there is little to no organized sports-specific conditioning prior to competition. The regularity of this participation can be negatively impacted by unit physical fitness training requirements along with job-specific training requirements. The basic concept of exercise

progression is often overlooked as multiple fitness requirements present simultaneously. Physical therapists and allied health-care assets assigned at the unit level can help mitigate many of these issues. The US Army currently assigns physical therapists to each brigade combat team (BCT) with the purpose of treating injuries, preventing injuries, and optimizing performance. The ratio of soldiers to each physical therapist makes fulfillment of these roles difficult. A large civilian sports team will often have one physical therapist and several athletic trainers working with their athletes. Having more than 100 athletes for one physical therapist is extremely rare. Army BCTs are comprised of about 3500 soldiers and have one physical therapist assigned. There are simply not enough sports-trained medical providers available in the military health system to assist in the management of multiple sports-related medical issues. As a result, the military model often becomes reactive to sports and exercise-related injury with proactive measures being difficult to integrate. A deficient planning stage for sports participation directly impacts the execution stage of sports performance and likely contributes to increased risk for musculoskeletal injury during these activities.

In the civilian setting, properly trained medical personnel are on-site for every organized sports practice and competition. Schedules are published and disseminated to all team staff members allowing for planning and preparation. In the military setting, there are often job-specific requirements that develop with little to no warning. As a result, available time for sports participation can vary greatly from week to week. When a time block for participation is available, military athletes often head directly into a sporting game situation with the players available at that time. This can mean that a military member is lining up for a flag football game wearing the very same running shoes he wore earlier that morning while completing a physical training run. The lack of appropriate footwear, combined with the seemingly unplanned sports competition occurring on the same day as normal unit physical training, are just two extrinsic but potentially modifiable injury risk factors in this scenario. The inability to plan and prepare for sports participation places these athletes in situations where their likelihood of injury is high. Once an injury occurs, the military model of health-care delivery is not always well suited to meet the high demands of athletes and soldiers. The integration of Sports Medicine and Reconditioning Team (SMART) clinic models is aimed at improving health-care delivery to soldiers by applying the sports medicine model that is utilized among traditional athletes [67].

Traditional health-care clinics utilize a primary care manager serving as a gatekeeper to specialty care clinics. SMART clinic models are being integrated into select Navy health-care facilities with the goal of improving patient access for the care of musculoskeletal injuries [67]. SMART clinics utilize an athletic training room setup with physicians, physical therapists, and athletic trainers working together to provide a multidisciplinary approach to treat acutely injured athletes. This organization allows for a greater number of patient visits and eliminates the delays in care associated with referrals to specialty clinics. There are limitations to implementation, with the most obvious being the lack of appropriately trained health-care providers in the military health system to deliver this style of care. Expanded utilization of the multiservice sports medicine post-professional programs offered

for physicians, physical therapists, and orthopedic surgeons is one way in which the number of appropriately trained health-care providers can be increased to meet the demand of military athletes. Supplementing core sports medicine teams in the military health system with allied health-care professionals with expertise in sports-related musculoskeletal injuries is also a model that has been gaining popularity in the military; however, these contract employees are typically fixed assets that would not deploy with military units, which is a limitation of this approach.

New Fitness Trends

In an effort to improve fitness while maintaining variety in their workouts, military athletes naturally follow trends that either claim to improve overall fitness or reduce the likelihood of injury. A few of these emerging trends include minimalist running, high intensity interval training, and urban obstacle course competition. While guided participation in any of these endeavors can result in impressive fitness gains, the lack of appropriate coaching or progression can result in significant injuries. While a misguided approach to minimalist running can produce overuse stress injuries of the lower extremities, urban obstacle courses can produce far more significant orthopedic injuries. Being cognizant of these emerging trends is important for all members of the military as the frequency of participation is only going to increase.

There is a popular shift occurring in the running community. Many runners are moving away from overly cushioned and protective shoes towards a more minimalist approach to running. Evolutionary design seems to indicate that the human foot is capable of withstanding the stress and strain associated with multiple forms of bipedal ambulation. The idea that human feet are fragile and need to be protected from surfaces and strains is advocated by some health-care providers and the commercial running shoe industry [68]. Some runners believe that the use of overly cushioned running shoes leads to an inherent change in running form [69]. This change in running form can hinder performance and lead to lower extremity injury. To counter these potential effects, some members of the running community are gravitating towards a more minimalist type of running shoe. Minimalist running shoes promote a more natural forefoot running style and reduce ground reaction forces found in rear-foot strikers [69]. While the current level of research is hardly conclusive, many minimalist runners advocate improved performance and decreased risk of injury with a forefoot running style [68, 70–72].

The allure of performance gains and reduced injury risk is certainly appealing to the military athlete. As a result, it is common to observe service members wearing minimalist running shoes and adopting a more forefoot running style. This transition in running equipment and style is not without risk. Several injuries, mainly in the foot, have been observed in minimalist runners [73]. When a transition to minimalist running is completed without adequate training and progression, bone stress changes in the feet can occur [74]. Resultant stress fractures of the metatarsals can

prevent soldiers from running or marching for at least 3–6 months as discussed in detail in Chap. 5. To reduce the risk of injury associated with the use of minimalist running shoes, it is imperative that runners receive adequate education, guidance, and training concerning this emerging fitness trend. Runners need to accept a minimum 3–6 month transition period if planning on adopting a minimalist running approach. There are definite gait pattern and force production differences when utilizing a minimalist forefoot running technique [68, 75]. During the transition to a forefoot running style, runners should also be prepared to significantly reduce their training volume and intensity as their body adapts to the new running style and altered biomechanics. Whether these gait pattern changes enhance performance and reduce injury, or predispose a runner to stress fractures and other overuse injuries is highly dependent on the training and transition approach utilized.

Another emerging fitness trend that promises rapid improvements in strength and endurance involves high intensity interval training (HIIT). Highly commercialized versions of this training are available from several different sources with perhaps the most popular being CrossFit. The purported fitness benefits achieved with HIIT seem to be directly compatible with the physical demands of many military occupations. Many soldiers understand that the current standardized version of military fitness is inadequate to prepare everyone for the explosive and high intensity demands associated with wartime tasks. Versions of HIIT adapted specifically for military tactical athletes have demonstrated improvements in measurable aspects of fitness while reducing the risk of injury [76]. The idea of high intensity circuit training is now being embraced in various forms on many military installations. While the fitness gains achieved with explosive high intensity interval training are obvious, so is the potential increased risk for injury. Performing maximal repetitions of an exercise to failure without adequate coaching can certainly lead to overuse injuries. Incorrect form combined with fatigue and the performance of explosive repetitions can set the stage for traumatic musculoskeletal injuries requiring months to heal. Awareness of HIIT is vital so military leaders at all levels can ensure that adequate coaching and facilities are available to correctly integrate this emerging form of physical fitness.

Utilizing endurance, strength, coordination, and agility is required to successfully navigate any number of man-made competitive obstacle courses. These commercialized ventures are touted as enjoyable ways to test various components of fitness. Some of these obstacle courses consist of tasks that are very similar to military training courses. The familiarity with these tasks combined with job-specific fitness benefits make urban obstacle course participation an appealing trend for military service members. Participation in these events is a relatively new trend and there are a wide variety of different obstacle course events available. As such, there is little information available concerning injury rates per participant. Military members participating in these events need to be aware that injuries, in some cases catastrophic injuries, do occur. Participating in events that are well-organized after undergoing a proper training regimen can help mitigate these injury risks.

The importance of physical fitness in the performance of military duties can be traced back to the earliest forms of organized armies. The movement patterns

required to perform military duties at the highest level are similarly reflected in the movement patterns encountered with several different types of sports participation. Military service members are often referred to as a microcosm of society. Therefore, the many sports and fitness trends encountered in the civilian world often find their way into military fitness training programs. These trends can often yield fitness and performance improvements, but they can also increase or alter the risk for musculoskeletal injury within military populations. The military is constantly balancing the performance benefits of sports and fitness program participation with the injury ramifications resulting from that very participation. With appropriate training, equipment, and adherence to basic exercise progression principles, military service members can continue to enjoy a variety of sports and fitness endeavors that enhance overall readiness while mitigating the risk for injury.

Summary and Conclusions

The strength and stamina of the American military service members will continue to play a deciding role in the outcome of future military conflicts. To maintain and improve on the physical aspect of readiness, the American military relies not only on formal physical training programs but also the integration of competitive and recreational sports. While sports participation helps to improve physical and mental fitness, as well as develop camaraderie and esprit de corps, these activities also predispose participants to the risk of musculoskeletal injury. It is incumbent upon military leaders to integrate an evidence-based approach towards improving fitness and lowering the rate of preventable injury through the integration of methods demonstrated in the peer reviewed literature.

The majority of research studies focusing on sports injury prevention and management involve civilian athletes at the collegiate and professional levels. Military health-care providers specializing in the delivery of sports medicine including physical therapists, orthopedists, and sports-trained physicians routinely integrate these research findings into the evaluation and management of injured soldiers. Advancements in the care of civilian athletic populations can have direct implications in the management of military athletes. Looking at the spectrum of care provided to civilian athletes, and the role of screening and injury prevention, can offer insight into the management of military sports and fitness injuries.

The benefits of sports participation cannot be outweighed by the risk of musculoskeletal injury. In addition to the obvious physical benefits, the added benefits in terms of mental resiliency and stress control are invaluable; however, poorly planned and executed sports and physical training programs can result in preventable injuries. Military leaders at all levels must find a way to mitigate the risk of injury while still reaping the rewards of sports participation. Through adequate planning, execution, and integration of health-care resources already available, sports and fitness events should continue as an integral part of military training without a detrimental effect on personnel and military readiness.

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References

1. Wakefield WE. *Playing to win: sports and the American military*. New York: State University of New York Press; 1997.
2. Dua A, Patel B, Kragh JF Jr., Holcomb JB, Fox CJ. Long-term follow-up and amputation-free survival in 497 casualties with combat-related vascular injuries and damage-control resuscitation. *J Trauma Acute Care Surg*. 2012;73(6):1517–24 (discussion 1524). doi:10.1097/TA.0b013e31827826b7.
3. Goldberg MS. Death and injury rates of U.S. military personnel in Iraq. *Mil Med*. 2010;175(4):220–6.
4. Tiesman HM, Peek-Asa CL, Zwerling CS, Sprince NL, Amoroso PJ. Occupational and non-occupational injuries in the United States Army: focus on gender. *Am J Prev Med*. 2007;33(6):464–70.
5. Sell TC, Abt JP, Crawford K, et al. Warrior model for human performance and injury prevention: Eagle Tactical Athlete Program (ETAP) Part II. *J Spec Oper Med*. 2010;10(4):22–33.
6. Haurer KG, et al. Frequency and causes of nonbattle injuries air evacuated from operations Iraqi freedom and enduring freedom, U.S. Army, 2001–2006. *Am J Prev Med*. 2010;38(1 Suppl):S94–107.
7. Lauder TD, Baker SP, Smith GS, Lincoln AE. Sports and physical training injury hospitalizations in the Army. *Am J Prev Med*. 2000;18(3 Suppl):118–28.
8. Jones BH, Cowan DN, Knapik JJ. Exercise, training and injuries. *Sports Med*. 1994;18(3):202–14.
9. Jones BH, Perrotta DM, Canham-Chervak ML, Nee MA, Brundage JF. Injuries in the military: a review and commentary focused on prevention. *Am J Prev Med*. 2000;18(3 Suppl):71–84.
10. Brawley S, Fairbanks K, Nguyen W, Blivin S, Frantz E. Sports medicine training room clinic model for the military. *Mil Med*. 2012;177(2):135–8.
11. Knapik JJ, McCollam R, Canham-Chervak M, et al. Injuries and injury prevention among senior military officers at the Army War College. *Mil Med*. 2002;167(7):593–9.
12. Tomlinson JP, Lednar WM, Jackson JD. Risk of injury in soldiers. *Mil Med*. 1987;152(2):60–4.
13. United States DoD. *Armed Forces Sports*. <http://armedforcessports.defense.gov/AboutAFS.aspx>. 2013. Accessed 10 April 2013.
14. Hipps T. *New Army Sports Program to pit battalion against battalion*. http://www.army.mil/article/100324/New_Army_Sports_Program_to_pit_battalion_against_battalion/. 2013. Accessed 10 April 2013.
15. Burnham BR, Copley GB, Shim MJ, Kemp PA. Mechanisms of basketball injuries reported to the HQ Air Force Safety Center a 10-year descriptive study, 1993–2002. *Am J Prev Med*. 2010;38(1 Suppl):S134–40. doi:10.1016/j.amepre.2009.10.009.
16. Burnham BR, Copley GB, Shim MJ, Kemp PA, Jones BH. Mechanisms of flag-football injuries reported to the HQ Air Force Safety Center a 10-year descriptive study, 1993–2002. *Am J Prev Med*. 2010;38(1 Suppl):S141–7. doi:10.1016/j.amepre.2009.10.010.
17. Burnham BR, Copley GB, Shim MJ, Kemp PA, Jones BH. Mechanisms of slow-pitch softball injuries reported to the HQ Air Force Safety Center a 10-year descriptive study, 1993–2002. *Am J Prev Med*. 2010;38(1 Suppl):S126–33. doi:10.1016/j.amepre.2009.10.008.

18. Owens BD, Cameron KL, Duffey ML, et al. Military movement training program improves jump-landing mechanics associated with anterior cruciate ligament injury risk. *J Surg Orthop Adv.* 2013;22(1):66–70.
19. Grindstaff TL, Hammill RR, Tuzson AE, Hertel J. Neuromuscular control training programs and noncontact anterior cruciate ligament injury rates in female athletes: a numbers-needed-to-treat analysis. *J Athl Train.* 2006;41(4):450–6.
20. Kuikka PI, Pihlajamäki HK, Mattila VM. Knee injuries related to sports in young adult males during military service—Incidence and risk factors. *Scand J Med Sci Sports.* 2011;23(3):281–7.
21. Jones JC, Burks R, Owens BD, Sturdivant RX, Svoboda SJ, Cameron KL. Incidence and risk factors associated with meniscal injuries among active-duty US military service members. *J Athl Train.* 2012;47(1):67–73.
22. Sikorski C, Emerson MA, Cowan DN, Niebuhr DW. Risk factors for medical disability in U.S. enlisted Marines: fiscal years 2001–2009. *Mil Med.* 2012;177(2):128–34.
23. Knapik JJ, Graham BS, Rieger J, Steelman R, Pendergrass T. Activities associated with injuries in initial entry training. *Mil Med.* 2013;178(5):500–6.
24. Knapik JJ, Graham B, Cobbs J, Thompson D, Steelman R, Jones BH. A prospective investigation of injury incidence and risk factors among Army recruits in combat engineer training. *J Occup Med Toxicol.* 2013;8(1):5.
25. Knapik JJ, Graham B, Cobbs J, Thompson D, Steelman R, Jones BH. A prospective investigation of injury incidence and injury risk factors among Army recruits in military police training. *BMC Musculoskelet Disord.* 2013;14:32.
26. Lisman P, O'Connor FG, Deuster PA, Knapik JJ. Functional movement screen and aerobic fitness predict injuries in military training. *Med Sci Sports Exerc.* 2013;45(4):636–43.
27. Kaufman KR, Brodine S, Shaffer R. Military training-related injuries: surveillance, research, and prevention. *Am J Prev Med.* 2000;18(3 Suppl):54–63.
28. Cowan DN, Bedno SA, Urban N, Yi B, Niebuhr DW. Musculoskeletal injuries among overweight Army trainees: incidence and health care utilization. *Occup Med (Lond).* 2011;61(4):247–52.
29. Knapik JJ, Darakjy S, Hauret KG, et al. Increasing the physical fitness of low-fit recruits before basic combat training: an evaluation of fitness, injuries, and training outcomes. *Mil Med.* 2006;171(1):45–54.
30. Brukner P, Khan K. Brukner & Khan's clinical sports medicine. 4th ed. Australia: McGraw-Hill Australia Pty Ltd; 2012.
31. Cameron KL. Commentary: time for a paradigm shift in conceptualizing risk factors in sports injury research. *J Athl Train.* 2010;45(1):58–60.
32. Prentice W. Principles of athletic training: a competency based approach. 14th ed. New York: McGraw-Hill; 2011.
33. Buist I, Bredeweg SW, Bessem B, van Mechelen W, Lemmink KA, Diercks RL. Incidence and risk factors of running-related injuries during preparation for a 4-mile recreational running event. *Br J Sports Med.* 2010;44(8):598–604.
34. Buist I, Bredeweg SW, Lemmink KA, van Mechelen W, Diercks RL. Predictors of running-related injuries in novice runners enrolled in a systematic training program: a prospective cohort study. *Am J Sports Med.* 2010;38(2):273–80.
35. Croisier JL, Forthomme B, Namurois MH, Vanderthommen M, Crielaard JM. Hamstring muscle strain recurrence and strength performance disorders. *Am J Sports Med.* 2002;30(2):199–203.
36. De Visser HM, Reijman M, Heijboer MP, Bos PK. Risk factors of recurrent hamstring injuries: a systematic review. *Br J Sports Med.* 2012;46(2):124–30.
37. Gribble PA, Brigle J, Pietrosimone BG, Pflie KR, Webster KA. Intrarater reliability of the functional movement screen. *J Strength Cond Res.* 2012;27(4):978–81.
38. Richmond, SA. et al. Is body mass index a risk factor for sport injury in adolescents? *J Sci Med Sport.* 16(5):401–5.
39. Emery CA, Meeuwisse WH. Risk factors for groin injuries in hockey. *Med Sci Sports Exerc.* 2001;33(9):1423–33.

40. Seward H, Orchard J, Hazard H, Collinson D. Football injuries in Australia at the elite level. *Med J Aust.* 1993;159(5):298–301.
41. Arnason A, Sigurdsson SB, Gudmundsson A, Holme I, Engebretsen L, Bahr R. Risk factors for injuries in football. *Am J Sports Med.* 2004;32(1 Suppl):5S–16S.
42. Brooks JH, Fuller CW, Kemp SP, Reddin DB. Incidence, risk, and prevention of hamstring muscle injuries in professional rugby union. *Am J Sports Med.* 2006;34(8):1297–306.
43. Brukner P, Nealon A, Morgan C, Burgess D, Dunn A. Recurrent hamstring muscle injury: applying the limited evidence in the professional football setting with a seven-point programme. *Br J Sports Med.* 2014;48(11):929–38.
44. Ekstrand J, Hagglund M, Walden M. Injury incidence and injury patterns in professional football: the UEFA injury study. *Br J Sports Med.* 2009;45(7):553–8.
45. Elliott MC, Zarins B, Powell JW, Kenyon CD. Hamstring muscle strains in professional football players: a 10-year review. *Am J Sports Med.* 2011;39(4):843–50.
46. Croisier JL. Factors associated with recurrent hamstring injuries. *Sports Med.* 2004;34(10):681–95.
47. Opar DA, Williams MD, Shield AJ. Hamstring strain injuries: factors that lead to injury and re-injury. *Sports Med.* 2012;42(3):209–26.
48. Roy TC, Knapik JJ, Ritland BM, Murphy N, Sharp MA. Risk factors for musculoskeletal injuries for soldiers deployed to Afghanistan. *Aviat Space Environ Med.* 2012;83(11):1060–6.
49. Cameron KL, Owens BD. The burden and management of sports-related musculoskeletal injuries and conditions with the US military. *Clin Sports Med.* 2014;33:573–89.
50. O'Connor FG, Deuster PA, Davis J, Pappas CG, Knapik JJ. Functional movement screening: predicting injuries in officer candidates. *Med Sci Sports Exerc.* 2011;43(12):2224–30.
51. Sugimoto D, Myer GD, McKeon JM, Hewett TE. Evaluation of the effectiveness of neuromuscular training to reduce anterior cruciate ligament injury in female athletes: a critical review of relative risk reduction and numbers-needed-to-treat analyses. *Br J Sports Med.* 2012;46(14):979–88.
52. Bennell KL, Crossley K. Musculoskeletal injuries in track and field: incidence, distribution and risk factors. *Aust J Sci Med Sport.* 1996;28(3):69–75.
53. Bennell KL, Malcolm SA, Thomas SA, et al. Risk factors for stress fractures in track and field athletes. A twelve-month prospective study. *Am J Sports Med.* 1996;24(6):810–8.
54. Bennell KL, Malcolm SA, Thomas SA, Wark JD, Brukner PD. The incidence and distribution of stress fractures in competitive track and field athletes. A twelve-month prospective study. *Am J Sports Med.* 1996;24(2):211–7.
55. Clement DB, Ammann W, Taunton JE, et al. Exercise-induced stress injuries to the femur. *Int J Sports Med.* 1993;14(6):347–52.
56. Croisier JL, Forthomme B, Namurois MH, Vanderthommen M, Crielaard JM. Hamstring muscle strain recurrence and strength performance disorders. *Am J Sports Med.* 2002;30(2):199–203.
57. Cameron KL. Commentary: time for a paradigm shift in conceptualizing risk factors in sports injury research. *J Athl Train.* 2010;45(1):58–60.
58. Kiesel K, Plisky PJ, Voight ML. Can serious injury in professional football be predicted by a preseason functional movement screen? *N Am J Sports Phys Ther.* 2007;2(3):147–58.
59. Chorbha RS, Chorbha DJ, Bouillon LE, Overmyer CA, Landis JA. Use of a functional movement screening tool to determine injury risk in female collegiate athletes. *N Am J Sports Phys Ther.* 2010;5(2):47–54.
60. Garrison M, Westrick R, Johnson M, Benenson, J. Association between the functional movement screen and injury development in college athletes. *Int J Sports Phys Ther.* 2015;10(1):21–8.
61. Gribble PA, Brigle J, Pietrosimone BG, Pfile KR, Webster KA. Intrarater reliability of the functional movement screen. *J Strength Cond Res.* 2012;27(4):978–81.
62. Teyhen DS, Shaffer SW, Lorenson CL, et al. The Functional Movement Screen: a reliability study. *J Orthop Sports Phys Ther.* 2012;42(6):530–40.

63. Shultz R, Anderson SC, Matheson GO, Marcello B, Besier T. Test-retest and interrater reliability of the functional movement screen. *J Athl Train*. 2013;48(3):331–6.
64. Dragoo JL, Braun HJ, Durham JL, Chen MR, Harris AH. Incidence and risk factors for injuries to the anterior cruciate ligament in National Collegiate Athletic Association football: data from the 2004–2005 through 2008–2009 National Collegiate Athletic Association Injury Surveillance System. *Am J Sports Med*. 2012;40(5):990–5.
65. Drakos MC, Taylor SA, Fabricant PD, Haleem AM. Synthetic playing surfaces and athlete health. *J Am Acad Orthop Surg*. 2013;21(5):293–302. doi:10.5435/JAAOS-21-05-293.
66. Hershman EB, Anderson R, Bergfeld JA, et al. An analysis of specific lower extremity injury rates on grass and FieldTurf playing surfaces in National Football League Games: 2000–2009 seasons. *Am J Sports Med*. 2012;40(10):2200–5. (Epub 2012 Sep 12).
67. Brawley S, Fairbanks K, Nguyen W, Blivin S, Frantz E. Sports medicine training room clinic model for the military. *Mil Med*. 2012;177(2):135–8.
68. Jenkins DW, Cauthon DJ. Barefoot running claims and controversies: a review of the literature. *J Am Podiatr Med Assoc*. 2011;101(3):231–46.
69. Lieberman DE, Venkadesan M, Werbel WA, et al. Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature*. 2010;463(7280):531–5.
70. Lieberman DE. What we can learn about running from barefoot running: an evolutionary medical perspective. *Exerc Sport Sci Rev*. 2012;40(2):63–72.
71. Cheung RT, Davis IS. Landing pattern modification to improve patellofemoral pain in runners: a case series. *J Orthop Sports Phys Ther*. 2011;41(12):914–9.
72. Rixe JA, Gallo RA, Silvis ML. The barefoot debate: can minimalist shoes reduce running-related injuries? *Curr Sports Med Rep*. 2012;11(3):160–5.
73. Salzler MJ, Bluman EM, Noonan S, Chiodo CP, de Asla RJ. Injuries observed in minimalist runners. *Foot Ankle Int*. 2012;33(4):262–6.
74. Ridge ST, Johnson AW, Mitchell UH, et al. Foot bone marrow edema after a 10-wk transition to minimalist running shoes. *Med Sci Sports Exerc*. 2013;45(7):1363–8.
75. Williams DS, 3rd, Green DH, Wurzinger B. Changes in lower extremity movement and power absorption during forefoot striking and barefoot running. *Int J Sports Phys Ther*. 2012;7(5):525–32.
76. Heinrich KM, Spencer V, Fehl N, Poston WS. Mission essential fitness: comparison of functional circuit training to traditional Army physical training for active duty military. *Mil Med*. 2012;177(10):1125–30.

Chapter 5

Musculoskeletal Injuries During Military Initial Entry Training

Scott D. Carow and Jennifer L. Gaddy

Introduction to Initial Entry Training (IET) Injuries

The American military consists of 3,663,100 [1] servicemen and women serving in active duty, National Guard, and reserve units in the Army, Navy, Air Force, and Marines who perform duties in a full spectrum of Military Occupational Specialties (MOS). To maintain appropriate troop levels, the military must recruit and access more than 180,000 new recruits every year [2]. Research shows that approximately 31 % of the recruits are discharged from the Army within the first 3 years of service. Approximately one third of these wash out within the first 6 months, one half within the first year, with the remaining recruits being discharged in the following 2 years [3]. The second leading cause of attrition is injury or illness, which contributes to 26% of separations within the first 6 months of training [3]. Musculoskeletal injuries account for more than 80 % of disability-related medical discharges among first-year recruits [4]. It is also likely that musculoskeletal injuries contribute to other causes of attrition such as failure to achieve standards for body composition or physical fitness standards. The National Research Council Committee on the Youth Population and Military Recruitment has stated that IET injuries are “the single most significant medical impediment to military readiness” [5].

Military recruits represent a broad cross section of the American population with recruits coming from all 50 states, as well as a small number of recruits who are legal permanent US residents who have not yet achieved American citizenship. Military recruits must be between 18 and 35 years at the time that they begin basic training; however, 17-year-olds may enlist with permission from their parents.

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Approximately 85% of all recruits are between 18 and 24 years and 21% are females [1]. Females have historically had a higher rate of first-term attrition with rates estimated at 1.1–1.8 times higher than their male counterparts [3]. Research is inconsistent concerning the role that age plays in the success of military trainees, but the available data seem to indicate the highest success rates among 19- to 24-year-old recruits, with attrition steadily increasing with increased age at the time of entry into military service [3]. Another demographic factor that affects attrition is whether or not the recruit is a high school graduate. Recent demographic information shows that 82% of all recruits between 1999 and 2008 had achieved high school graduation [1]. Research shows that recruits who have not graduated from high school are approximately twice as likely to leave military service than those who have achieved high school graduation [3].

Military Entrance Processing Station Physical

Before joining the military, a recruit must complete a two-part physical examination at the Military Entrance Processing Station (MEPS). The MEPS physical includes a comprehensive patient history, blood and urine testing, hearing and vision testing, and baseline body composition testing. While all prospective service members must meet certain baseline standards, applicants for certain specialties may have to meet higher admission standards. For instance, an individual who is enlisting to serve in Special Forces or an airborne infantry unit must meet higher fitness standards than an individual enlisting to serve as a mechanic or a cook. It is also possible for a recruit to obtain a waiver for a disqualifying musculoskeletal condition. Nearly all musculoskeletal surgeries and many musculoskeletal conditions are considered disqualifying conditions for military service; however, if the recruit obtains a letter from their doctor stating that they have completed rehabilitation and have no lingering disability, then they may be eligible for a waiver. Historically, recruits who obtain a waiver for a prior history of back or knee injuries have an increased rate of attrition in the Army, although this increase in attrition is not seen in other branches of service [3].

IET Requirements

To serve in the US military, one must complete IET. In the Army, recruits start with Basic Combat Training (BCT), which is an introduction to basic military skills such as customs and courtesies, military values, and basics of first aid and rifle marksmanship. Regardless of their MOS, all recruits must complete BCT, which consists of 10 weeks of military training including many vigorous physical requirements. The standard physical requirements for Army BCT include marching with combat

gear and a 40-pound rucksack or backpack for distances starting with 4 km and progressing to a final distance of 16 km [6]. The marching standards are the same for all recruits, regardless of gender and age. All recruits must also pass a physical fitness test, which consists of 2 min of pushups, 2 min of sit-ups, and a timed 2-mile run. The standards for physical fitness testing are variable based on age, gender, and branch of military service. In addition to these mandatory testing requirements, all recruits participate in many physical events such as obstacle courses and physical readiness training, which serves to improve physical fitness and to prepare recruits for military service. While these physical tasks are necessary to ensure military readiness, they also put recruits at risk of musculoskeletal injury, which is a major concern for IET commanders. According to one recent review of IET attrition, musculoskeletal injury accounts for 5–10 times as many limited duty days as illness and is associated with 6–8% of all recruit attrition [3].

Estimating the Cost of Injuries

Estimating the cost to the government incurred from IET injuries is very difficult because it is highly variable. There are substantial fixed costs associated with attrition including recruiting, accessing, training, equipping, and paying recruits during their brief periods of service. The estimated recruiting cost was \$22,898 per recruit in FY2010 [2]. However, this is only one small portion of the cost of attrition, as each of these recruits incurs costs associated with training, equipping, housing, and pay during their brief terms of service. There are other additional costs, which are highly variable depending on the reason for dismissal from service. These costs include medical costs associated with examination, imaging, treatment, and rehabilitation of injuries incurred during training. The most recent reported estimate for the cost per discharged recruit was \$57,500 in 2005 [30]. With an estimated 31% attrition rate for approximately 180,000 recruits, attrition represents approximately \$3 billion in annual costs to the military. The costs associated with injuries of recruits who remain in the service are even more difficult to quantify but are still significant. For instance, many recruits with stress fractures are removed from training in order to rehabilitate their injuries for several months. After 3–6 months of recovery, these recruits often successfully resume training. In these cases, there are substantial costs including multiple imaging studies, rehabilitation, and lost training time. In addition to these medical costs, in most cases, the military continues to pay the salary, housing and meal costs for trainees while they recover from their injuries.

Musculoskeletal injuries to military recruits fall under two broad categories: acute traumatic injuries and chronic overuse injuries. Overuse injuries in this population, which are the primary focus of this chapter, include not only primarily bone stress injuries but also soft tissue injuries such as patellofemoral pain, iliotibial band friction syndrome, most instances of low back pain, and various tendonopathies of the lower extremity. Traumatic injuries include ankle sprain, acute traumatic knee

joint injuries, shoulder dislocation, and various fractures. Prevention strategies for these injuries are often complicated as it is important to minimize risk while continuing to provide challenging training opportunities to prepare recruits for the rigors of military service.

Bone Stress Injuries

Stress injuries, which include stress reactions and stress fractures, are overuse injuries that occur in bones bearing heavy weight, most frequently reported in the tibia, femur, and metatarsals [7–9]. Stress fractures can be attributed to the overloading of normal bone through sudden increase in exercise or when normal loading is applied to abnormal bone. The underlying mechanisms causing stress injuries are still being studied, but in general, mechanical pressures from increased weight bearing and activity stimulate the bone remodeling process. Bone resorption occurs at a faster pace than bone formation, resulting in a period where the bone is weakened and susceptible to stress injuries [10, 11]. Stress fractures can be healed by two methods: remodeling and adaptation. Remodeling is the primary means of early recovery because the adaptation process occurs more slowly [12]. Stress fractures are a major cause of loss of training in the military, specifically among recruits with strenuous training programs [13]. Most US studies show that 1–9% of military trainees will sustain a stress fracture [14–16]. These injuries take a significant amount of time to heal and often require recruits to drop out of training or be “re-cycled” where they have to start their training over once their injury has healed.

Risk Factors for Bone Stress Injuries

Risk factors for stress injuries can be divided into two categories: modifiable and non-modifiable (Table 5.1). Modifiable risk factors are those factors that can be treated or controlled. It is important to identify these risk factors as they provide the most likely opportunity to mitigate injury risk. Non-modifiable risk factors are those risk factors that cannot be changed such as age, gender, or ethnicity. While these non-modifiable risk factors cannot be affected directly, it is still important to be aware of them as awareness of non-modifiable risk factors may enable unit leaders and medical providers to focus their injury prevention efforts on those trainees with the greatest risk of injury.

Researchers have found several non-modifiable risk factors for stress fracture in trainees. One factor that increases risk is gender with multiple studies indicating that female recruits are more susceptible to stress injuries when compared to males in the same training environment [17–23], with females experiencing an incidence of stress fracture that is 2–10 times higher than males [17, 18, 20, 24–29]. This can

Table 5.1 Modifiable and non-modifiable risk factors in the causation of stress fractures

Modifiable risk factors	Non-modifiable risk factors
Body mass index	Gender
Muscle strength	Age
Pretraining fitness level	Ethnicity
Nutrition factors	Lower extremity morphology
Menstrual dysfunctions	Genetics
Muscle fatigue	Previous injury history
Flexibility	
Training errors	
Training surfaces	
Worn-out/inappropriate footwear	
Excessive training intensity	
Environment	

be related to predisposition for the female athlete triad [30, 31] as well as females general decreased muscular strength compared to males. Increasing age is more commonly associated with an increase in stress injuries [17, 32], but in one study by Milgrom et al. [33] it was reported that the younger the trainee, the more susceptible to fracture due to lack of fully developed bony strength. Risk of stress fracture decreased by 28 % for each additional year in age between 17 and 26 years. It is also reported that narrow bones in relation to cross-sectional width have a higher incidence of stress injuries [34–37]. This may also predispose females to stress fracture injury risk. White recruits have shown increased incidence of stress fractures when compared to African-American, Hispanic, and Asian recruits[17, 32, 33].

Many of the risk factors relating to stress fractures are closely related to the recruit’s fitness and nutritional habits prior to enlistment. One societal factor that may contribute to increased risk of stress fracture is the fitness level of American youth. Some research has suggested that aerobic fitness levels of American youth are declining [38]. However, there is conflicting research as Knapik et al. found no change in male fitness levels VO2max from 1975 to 1998 and slightly improved aerobic fitness in females during the same timeframe [39]. In more recent Army research, the failure rate for the initial fitness assessment has increased in males from 4 % in 2003 to 34 % in 2009 with female failures increasing from 10 to 47 % during the same timeframe [39]. As previous fitness, nutrition, and muscle strength are lower or decreased, incidence of stress fracture increases. When high body mass index (BMI) is related to poor physical conditioning, stress fractures increase [18]. Similarly, recruits (particularly, females) in the lower quartile for BMI are also at increased risk for stress fracture suggesting a bimodal effect of BMI on stress fracture risk [40]. Multiple studies of US Army recruits have consistently shown that trainees, both men and women, with less lean mass in the lower leg and thus smaller calf girth measurement are more likely to incur stress injuries [41–44]. Trainees in these studies performed fewer sit-ups during a timed test, correlating to lower muscle strength and endurance, and also ran slower [45]. Soldiers who participated in

low-impact sports such as swimming prior to reporting to training had an increased stress fracture risk versus trainees who participated in basketball [46]. Those who did not participate in any physical activity before training, although not statistically significant, were also highly susceptible to stress injuries. There have been many recent studies that utilize statistical shape modeling, but they are very labor intensive and would likely not be feasible for large-scale screening in a military training environment [47–51]. A recent study by Yanovich et al. [23] attempted to link anemia and iron deficiency to stress fractures. They found a 6.6% prevalence of stress fractures among female soldiers at the end of training, of which 28.6% were anemic and 23.6% were iron deficient on recruitment day.

Modifiable risk factors may include training errors, training surfaces, footwear, and environmental conditions. These risk factors can essentially be controlled and should be decreased as much as possible in order to help prevent stress injuries. Training errors that are typically associated with increased stress injuries are increasing mileage or intensity (e.g., hill running) too rapidly [14, 20]. The type of running and marching surface is also an important activity on pavement that leads to increased impact when compared to running on a rubber track or grassy surface [52]. In an Israeli Defense Force (IDF) study, stress fracture incidence increased from the usual report of 3.5 to 11.4% when the only change in training was a switch to marching on hilly, rocky terrain instead of flat, predictable terrain [53]. When the marching returned to flat terrain, the incidence of injuries returned to 2.5%.

The discussion of training footwear includes both boots and running shoes. Although there is no evidence to show that specific types of running shoes for specific foot types decrease the overall incidence of stress injuries, much research has investigated the use of insoles and types of boots. A Cochrane database review that suggests that insoles might reduce stress fracture rates [54] is in agreement with Milgrom et al. [9] who noted a reduction in stress fractures with the use of specifically shock absorbing orthoses as opposed to other types of orthoses. The IDF uses specific Zohar boots that have been shown to reduce tibial strain contributing to less stress fractures [55, 56].

The ideal infantry trainee would be male, African-American, should have wide bones, a low range of hip external rotation, a low-normal foot arch, be beyond teens in age, and have played basketball regularly for more than 2 years prior to enlisting. As the above stated ideal trainee is often not attainable, clinicians would greatly benefit from a prediction rule for stress fractures to use as a screening device for those trainees who do not fit the perfect mold. Moran et al. [49] published a study specifically analyzing female trainees and factors that lead to developing stress fractures. They collected data on body mass, aerobic capacity, nutrition, and hematological values. They concluded that a young female is at greater risk if she is tall, lean, feels “burnout,” has iron deficiency, and is at the end of the normal ferritin range. A follow-on study was then performed for male infantry recruits. They collected data on anthropometric variables, fitness variables, bone quality, a hematology profile, and questionnaires on activity level prior to training, a psychological assessment, nutrition assessment, and health history for a total of 77 variables. The prediction model was constructed of three variables: aerobic

training (times per week), aerobic training duration (minutes per week), and waist circumference [50]. They concluded that a young male recruit is at a greater risk of developing a stress fracture if, before entering training, he ran less than 2 times per week and each training was greater than 40 min and if his waist circumference was less than 75 cm. This model was found to be able to correctly predict the presence or absence of stress fractures in 85 and 76% of the two sample populations. With these easily screenable metrics for male and female trainees, injury prevention techniques by cadre and clinicians can be implemented with little lost training time or additional cost.

Bone Stress Injury Assessment and Diagnosis

If stress injuries cannot be predicted then they must be evaluated and treated as quickly as possible in order to ensure proper healing and reduce the possibility of comorbidities. A good clinical exam is the first step to identifying a trainee with a stress injury. Both the soldier's history and objective exam can lead you to suspicion of injury, but in many cases it is necessary to order radiological imaging to confirm the diagnosis. Radiological imaging includes plain film radiographs, scintigraphy (bone scan), magnetic resonance imaging (MRI), and computed tomography (CT). Although plain films are commonly used as the initial standard, they have limited usefulness during the early stages of development of a stress fracture [57–67]. If positive, radiographs are diagnostic. Radiographs will usually be positive approximately 1–3 weeks after initial report of injury [68]. While standard radiographs are very specific for stress fracture, they lack adequate sensitivity. Currently, the gold standard for diagnosis is either triple-phase technetium-99m bone scan [64–66] or MRI [69, 70]. Bone scan has been reported as having a sensitivity of 100% and specificity of 76% [58, 66]. It is important to realize that a bone scan may pick up increased uptake of the radioisotope due to normal bone remodeling from increased training stress [21]. Therefore, results from a bone scan cannot be used to diagnose a stress injury in an area that is non-symptomatic. A study of asymptomatic Army trainees found that 98.4% of pain-free trainees had positive bone scans during the 7th week of training [71, 72]. Bone scans may also remain positive for up to a year after the initial injury and should not be used as a tool for evaluation of healing. A negative bone scan does not always eliminate the possibility of a stress fracture. When treating soldiers with suspicion of femoral neck or pelvic stress injuries, it is important to note that studies have documented false-negative bone scans in these areas. If symptoms continue, further imaging may be needed. MRI has been shown to have comparable sensitivity to bone scan [57, 66] and superior specificity [66]. MRI is not commonly used for diagnosis due to its cost [57, 67] and even with high sensitivity and specificity, it cannot be used without limitation. Early tumors, osteomyelitis, and bone bruises also produce stress-like findings [73]. Previous studies have shown that for an accurate diagnosis of bone stress injuries in the pelvic and femoral area, MRI should be

used [7, 74]. CT is not commonly used in assessment of stress fractures but can be used as an adjunct to the further assessment of known stress injuries, particularly in the navicular bone of the foot and the sacrum [73, 75].

If radiological imaging is unavailable, history and clinical exam should be used instead of other, unproven, or unreliable clinical assessments such as therapeutic ultrasound or tuning forks. Previous studies have suggested the use of ultrasound to elicit pain when applied over the fracture site as a diagnostic tool [11, 58, 64]. The results of the meta-analysis by Schneider et al. in 2012 shows ultrasound to have a sensitivity of 64% and specificity of 63% [76]. Though this shows a low to moderate performance, the likelihood ratios are small. Tuning forks have also been suggested as effective diagnostic tools for stress injuries. The tuning fork is applied over the suspected fracture site looking for a pain response due to irritation of the damaged periosteum [66, 77]. A poorly conducted study by Wilder et al. [70] compared the ability of 128, 256, and 512-Hz tuning forks to MRI and bone scan in 45 males. The 256-Hz tuning fork had 90% sensitivity for detecting tibia stress fracture; however, the specificity was only 20%. The 512-Hz tuning fork showed 83% sensitivity and 50% specificity for detecting tibia stress fractures. With these results, it is recommended that radiological imaging be used for the confirmation of stress fractures.

Hip, Pelvis, and Upper Leg Stress Injuries

Soldiers who report to medical treatment facilities complaining of hip pain should be screened for bone stress injuries in the areas of the femoral neck, pelvis, and femur. Femoral shaft and pelvic stress injuries, including the inferior pubic ramus (IPR), superior pubic ramus (SPR), and sacrum, are generally considered low risk and tend to heal without continued symptoms allowing the soldier to return to and complete training. Femoral neck stress injuries (FNSIs) are much less common, but high risk, and both providers and company staff should be aware of their signs and symptoms. Differential diagnosis of hip/pelvic stress injuries includes acetabular impingement, Iliotibial band (ITB) friction syndrome, greater trochanteric bursitis, sacroiliac joint pain, radicular low back pain, or muscle strain.

Femoral Neck Stress Injuries

FNSIs represent 5–10% of injuries that occur during IET, [13, 78], but are by far the most costly than most training injuries with an estimated cost of nearly \$100,000 per injured trainee. There are two classifications of FNSIs: compression-side injuries and tension-side injuries. Compression-side injuries are the most common and most are treated nonoperatively [79]. Tension-side injuries are of much higher risk due to the risk of displacement and normally require operative fixation. Risks that

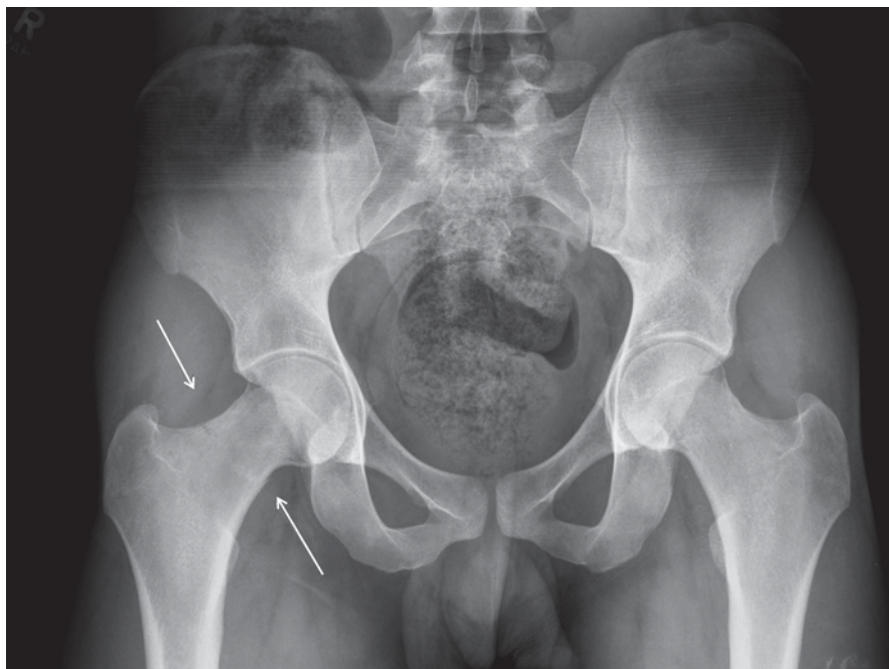


Fig. 5.1 Grade 4 stress fracture of the femoral neck

are associated with displaced FNSIs include avascular necrosis and severe osteoarthritis [80]. Recruits who sustained FNSIs during training were found to be at a 25% higher risk to sustain stress fractures in future training [46].

Clinical signs and symptoms for FNSIs are very general, which often make diagnosis challenging. Most soldiers will not complain of pain until about 4–7 weeks of training [81] or 13–16 weeks [82]. The typical presentation is poorly localized groin or thigh pain including intermittent, tight sensation in the groin after activity, and increased pain while climbing upstairs or taking downstairs [59, 83]. Clinical exam may reveal pain at end ranges of hip motion testing, especially internal rotation, and pain with a single leg stance or hop; however, the single leg hop test has been discontinued in the US Army IET medical facilities when a suspected FNSI is considered a differential diagnosis due to the possibility of causing displacement of the stress fracture. Risk factors include coxa vara, female gender, nutritional deficiencies, and decreased bone mineral density [84–88]. Higher age, poor muscle strength, and a poor result in the 12-min run test are significant risk factors for FNSIs reported from Finnish military training [89].

If a FNSI is suspected from the clinical exam, X-ray is ordered to rule out grade 4 fracture (Fig. 5.1). If the plain films show no fracture, bone scan is ordered. Bone scan has been shown to have very high sensitivity, but moderate specificity, so results from a bone scan cannot be interpreted independent of a physical exam. Even if the bone scan returns negative, if the patient is not progressing through normal

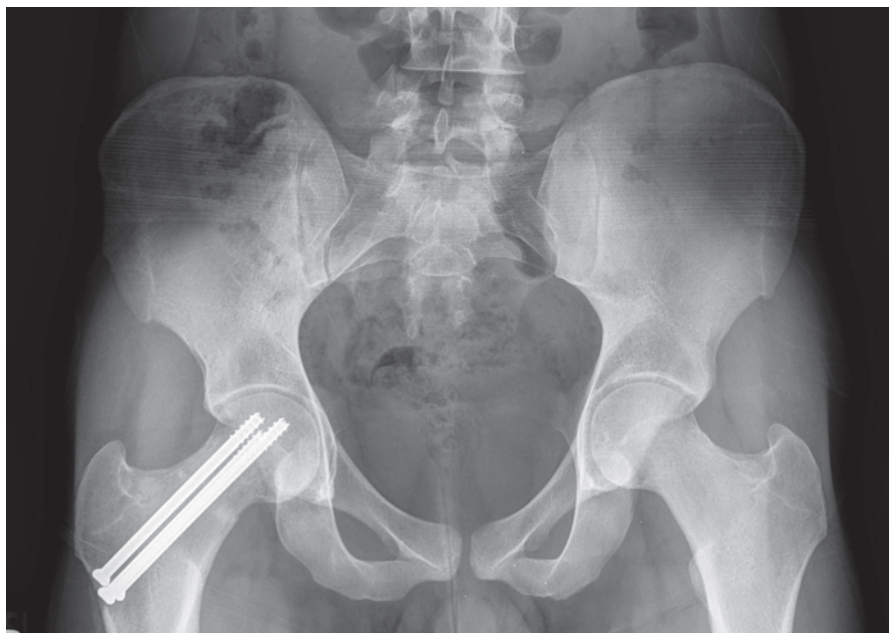


Fig. 5.2 Open reduction and internal fixation of femoral neck stress fracture

treatment with physiological signs of healing, an MRI can be ordered. MRI is the gold standard for identifying femoral neck stress fractures due to its high sensitivity and specificity, but due to cost and availability, X-ray and bone scan are generally performed prior to MRI as a fracture can be seen utilizing these imaging techniques as well.

Treatment for FNSIs is very patient and symptom-dependent and can involve both operative and nonoperative treatment, depending on severity and location of injury. Nonoperative treatment generally consists of crutch ambulation with partial or weight bearing as tolerated restrictions on the affected hip during the first 4–6 weeks after diagnosis of injury. This is followed by 4–6 weeks of nonimpact cardiovascular training with light strengthening and stretching in a pain-free range of motion. This progresses to 4–6 weeks of return to impact and running, with the first 3–4 weeks of run training performed on a treadmill, later returning to running outside. At this point, depending on residual symptoms and the MOS per week of training, the soldier may be reintroduced back to mainstream training.

Operative treatment is indicated for compression-sided fractures measuring 50% or greater of the femoral neck width and any tension-sided fracture, or completed fractures. Surgical intervention includes pinning of the femoral neck (Fig. 5.2). There is risk of further complication after surgical intervention including avascular necrosis of the femoral head, malunion, or nonunion.

Outcomes for trainees in a stressful IET environment are very subjective and difficult to standardize. In a study by Weistroffer et al., despite appropriate treatment

for FNSIs as evidenced by the absence of additional complications, many of their patients still complained of pain in their hips 5–7 years after surgery [90]. Issues of secondary gain cannot be ruled out. In the military setting, if a soldier is not recommended to return to training due to continued complaint of pain or inability to rehabilitate their injury fully, they are sent to the Medical Evaluation Board. This can be a lengthy process, even for a soldier who has been in the military for less than 6 months, and can end up creating other negative consequences.

Time lost from training due to injury varies depending on the significance of the injury. If detected early, a femoral neck compression-side stress injury of less than 50% width can rehabilitate normally in 3–4 months. If an injury has progressed to requiring surgery, the length of rehabilitation time is increased and the likelihood of successfully returning to training is decreased.

Pelvic Stress Injuries

The most commonly treated pelvic stress injury seen in IET is the inferior pubic ramus (IPR) stress injury. If not treated early, these injuries can progress to include the superior pubic ramus (SPR) and sacrum. IPR/SPR stress injuries are caused by the repetitive stress on the adductor muscle group attachments on the inferior or superior pubic ramus (adductor magnus, brevis, gracilis, pectinius, and obturator externus). When soldiers are made to “stride out” during marching movements, this muscle group is on a repetitive stretch and contract motion that can be outside of soldiers’ comfortable range and strength limits. This repetitive overstretching and activation, coupled with fatigue in hip stabilizing muscles from the marching activity, can lead to increased stress on that bony area, promoting stress injury [15, 91].

Clinical signs and symptoms include pain with palpation over the IPR, pain with resisted adductor testing, and pain with hip flexion. The soldier may complain of pain with running and performing sit-ups. The current practice guidelines at all US Army IET medical facilities are to immediately place the soldier on crutches and order imaging. Regular radiographs are ordered first, in order to rule out a fully progressed stress fracture. If radiographs are normal and the soldier is still complaining of pain, bone scan or MRI is ordered as deemed fit. There are not many researched intrinsic or extrinsic risk factors specifically linked to pelvic stress injuries. They are more commonly reported in females when compared to males in the same training units. In 1991–1992, pelvic stress fracture incidence of 11.2% was reported in an Australian study of female Army recruits. In the following year, 0.1% incidence was recorded in the same training unit for males [91].

Treatment for pelvic stress injuries is similar to that of FNSIs. Treatment starts with crutch ambulation until walking without the assistive device is pain free and then progresses to light nonimpact cardiovascular exercises and stretching. Once clinically and radiographically cleared for signs of healing, slow return to activity, specifically running and ruck marching is introduced. Hip, gluteal, and general lower body strength training is used to help prevent this injury from recurring when placed back in training.

It is difficult to state time lost from training due to injury as this is dependent on timely diagnosis and the extent of injury, as well as the recruit's motivation to return to training. In general, trainees with pelvic stress injuries that have progressed to stress fracture are removed from training, rehabilitated for 2–4 months before returning to training. Also dependent on training time lost is how far the soldier made it in training and the training requirements for specific units.

Femoral Shaft Stress Injuries

Femur stress injuries often present as quadriceps muscle strains or knee pain. Clinical signs and symptoms include low level of pain with impact activities, a positive fulcrum test [92], and/or pain over the injury site. Lacking the protection of significant pain in the presence of femoral stress fracture, these injuries are more likely to progress to full fractures [93]. The most common location for a femoral shaft injury is on the medial (compression) side of the femur, which is the attachment site for the adductor and vastus medialis muscle groups. Rarely are condylar stress injuries seen, but they are reported both medially and laterally [30, 94, 95]. Femur stress injuries tend to heal faster than other stress injuries with activity modification and slow return to impact [30]. Depending on the severity of the injury, some femur stress injuries can be left in training if they are allowed a decrease in running and activity level.

Lower Leg Stress Injuries

Leg stress injuries include the areas of the medial tibial plateau, tibial shaft, medial malleolus, and fibula. Exercise-induced stress fractures are common in the lower extremities, with 75% occurring in the tibia [96]. Occurrence of this injury in the general athletic population is less than 3.7% [92, 97, 98], but is reported anywhere from 0.9 to 64% in military recruits [17, 18, 28, 36, 95, 99, 100]. In a study by the IDF, data on 392 trainees showed that greater static valgus alignment of the knee was a significant risk factor for tibial stress injuries, but additional research is still needed [99].

Tibial Stress Injuries

Tibial shaft stress fractures are the most common anatomical region of involvement in trainees and athletes (Fig. 5.3) [25, 101]. Other diagnoses that must be ruled out are shin splints, compartment syndrome, or other lower leg muscular overuse symptoms. Symptoms include increased pain with impact activities, pain with palpation over the injury site, and sometimes pain with resisted ankle muscle testing. Tibial

Fig. 5.3 Tibial shaft stress fracture



stress fractures are often characterized by a high level of pain even in the early stages of stress injury [93]. Batt et al. reported that positive findings on a bone scan read as shin splints can be considered as the beginning of stress-related changes to the tibia and should be treated as such to prevent progression to stress fracture [102]. When the tibia is divided into proximal, mid, and distal 1/3, most injuries that are diagnosed by clinical exam and radiographs are reported in the middle third of the shaft, versus when MRI is used as the imaging technique and injuries in the distal 1/3 of the tibia are more frequent [9, 103–106]. When MRI was used, lower level stress injuries (grades 1–2) to the distal 1/3 of the tibia were seen more frequently. Treatment for tibial stress injuries includes reduction of impact activity and slow return to training as symptoms subside. Midshaft stress fractures have reports of the poorest outcome with regard to returning to military training whereas proximal tibial stress fractures have reports of good potential for return to training [107]. Because of the increased report of pain with these injuries, most trainees are pulled from training before they develop into actual fracture, leading to reduced healing time and return to activity.

Fibular Stress Injuries

Fibular stress injuries are less common as the fibula is not a significant weight-bearing bone. These types of stress fractures are attributed to muscle traction and torsional injuries. A soldier who primarily runs or marches on the outside of their feet may have an increased likelihood of developing this type of injury. Differential diagnosis includes muscle strain and compartment syndrome. Only 0–1 % of fractures reported among Israeli military recruits were reported as fibular stress injuries [9, 99].

Foot Stress Injuries

Foot stress injuries commonly diagnosed during military training frequently impact the metatarsals, tarsals, and calcaneus. Some research suggests that foot arch height may influence the risk of stress fracture with associated intense physical training, but more research is needed to determine the association between arch height and type of stress fracture [15, 108]. Pes planus has been found to be a protective factor for stress fractures in basic training with a report of only 10 % incidence of stress fractures in trainees with this foot type versus 39.6 % incidence among trainees with high arches and 31.3 % incidence of stress fractures in trainees with average arches [109].

Metatarsal Stress Injuries

Metatarsal stress injuries, also known as fatigue or march fractures, have been documented as a medical condition in the military since 1855 [110]. The most common locations of stress fractures of the metatarsals are in the second and third bones. A stress fracture of the base of the fifth metatarsal is less common but of a higher risk. Clinical signs and symptoms include pain with palpation, most commonly on the dorsum of the foot, pain with axial loading, and fulcrum testing. Differential diagnosis includes metatarsalgia, Morton's neuroma, and tendon strains. Frank metatarsal stress fractures are often completely asymptomatic until a complete fracture occurs. Milgrom et al. reported that soldiers who were completely asymptomatic prior to a long ruck march finished with a fracture of one or two of the metatarsal cortices [37]. When comparing incidence of stress injuries and body part, tibial and femoral shaft often outnumber metatarsals. But when examined over the course of a year of training, both tibial and femoral stress injuries did not occur after week 28, whereas metatarsal stress injuries continued to occur [93]. By measuring in vivo strains at both the second metatarsal and tibia, it was found that simultaneous strains in the metatarsals were four times higher than those of the tibia during

both treadmill walking and running. With this information, it can be deduced that metatarsal stress fractures can be caused by cyclic overloading alone, without the addition of a remodeling response to increased activity [93]. Treatment includes decreased weight-bearing status until pain free with gradual return to impact activities. It is important to allow the trainee to start putting stress (weight) on the affected area once they are pain free in order for the remodeling process to occur [111]. In a case report written by a military physical therapist stationed at Fort Sam Houston, a trainee was treated very conservatively with crutches, a walking boot, and 1 month of convalescent leave. The trainee was not given any exercise program while on convalescent leave and once she returned, she was started in an aquatics program. Her healing time was most likely significantly delayed due to the lack of stress on the bone while on leave. Depending on how quickly the metatarsal stress injury is diagnosed, the length of the training time lost will be determined. If the symptoms are caught early, the soldier may be allowed to stay in training if they can limit impact activities. If the injury progresses to full fracture, normal treatment is 4–6 weeks of no running or significant impact with slow return to activity, which is dependent on the symptoms.

Calcaneal Stress Injuries

Calcaneal stress injuries are considered to be fairly common in athletes and military recruits [23, 112–114]. Previous research on calcaneal stress injuries found the posterior part of the bone to be the most frequently involved, but these studies had been performed over 30 years ago when MRI and bone scan were not readily available [114–116]. Clinical symptoms include pain with palpation or squeezing of the calcaneus, pain with impact activity, and sometimes foot swelling. Differential diagnosis includes retrocalcaneal bursitis, Achilles tendonitis, plantar nerve entrapment, radiculopathy, and posterior ankle impingement [117, 118]. In one Finnish study by Sormaala et al., the trainees were evaluated by an orthopedic surgeon for stress injury symptoms and plain radiographs were taken of the most symptomatic area [119]. The patients were then evaluated with MRI. Of the injuries, 56% were located in the posterior part of the bone, which is much less than the previously reported 95–100% [114–116]. Another 26% were located in the anterior portion and 18% in the middle portion of the bone. With a clearer diagnosis of area of stress injury with the use of MRI, injuries to the anterior calcaneus were also associated with injuries of the cuboid and talus. When performing the clinical exam and follow-up exams, it is important to check other areas of the foot for concomitant stress injuries. Of all the stress injuries of the calcaneus that were detected with MRI, only 15% were detected on radiographs. Patients are managed with reduced activity and very rarely is casting necessary. Recovery and likelihood of return to duty status is good following calcaneal stress injury.

Tarsal Stress Injuries

Tarsal stress fractures most commonly include stress injuries to the talus and navicular, but may involve the cuboid and cuneiforms. Matheson et al. reported longer recovery times for injuries to these areas when compared to stress injuries in the lower extremity due to delayed diagnosis [101]. The clinical exam should consist of complete palpation of the foot to get a clearer idea of point of pain origin and followed with diagnostic imaging. Stress fractures of the talus have been associated with excessive subtalar joint pronation [120, 121]. Stress fractures of the navicular typically present as vague dorsal foot pain. Squeezing the midfoot will elicit symptoms. Differential diagnosis includes tendonitis or a symptomatic accessory navicular bone. Patients are managed with reduced activity and the likelihood of return to full duty status is good.

Anterior Knee Pain

One of the most common problems among trainees is anterior knee pain, which has been called the “black hole of orthopedics” [8]. Anterior knee pain can be a chronic and disabling condition. Also known as patellofemoral pain, or more colloquially as “runner’s knee,” this condition represents a challenging problem for clinicians which is extremely difficult to treat. Its causes are not clearly established, although it may be related to poor physical fitness, poor bony alignment, or abnormal lower extremity movement patterns [122]. Because its causes are not clearly understood, definitive prevention and treatment options remain elusive as well. Primary treatment of anterior knee pain usually consists of physical therapy focused on restoring normal lower extremity movement patterns and strengthening and stretching lower extremity musculature. Evidence to support exercise therapy for anterior knee pain is lacking though as few trials have compared physical therapy treatment to a placebo. Like many other conditions that affect trainees, one of the best treatment options for the trainee with anterior knee pain is rest. However, it is usually difficult to provide adequate rest to the trainee with anterior knee pain while still enabling him or her to complete the physical requirements of IET. Anterior knee pain is particularly concerning because of the strong likelihood of prolonged pain and disability. In one study, nearly half of Israeli recruits who developed anterior knee pain during training continued to have symptoms 6 years after the completion of training [55].

Trainees suffer from numerous other overuse injuries of the lower extremity including plantar fasciitis, iliotibial band friction syndrome, and various tendinopathies of the lower extremity. However, as these injuries are not unique to the basic training environment, they will be discussed in another chapter.

Low Back Pain

Another problem that affects a large number of trainees is low back pain. Research suggests that low back pain accounts for more than 9% of the trainee medical discharges within the first 180 days of service [123]. It is estimated that low back pain affects up to 50% of the young adults in civilian and military populations by the age of 20 [120]. This risk is potentially increased among trainees who must carry loads up to 40 pounds for distances up to 12 miles. Research shows that the axial loading caused by carrying a loaded rucksack affects the kinematics of the low back causing a significant increase in lordosis while under load [124]. While research has not investigated the differences between genders, it seems that these effects would be more pronounced in female trainees who typically weigh less than their male counterparts but are required to carry the same loads.

Another factor affecting low back pain is the military requirement to perform sit-ups as part of the physical fitness test and as a regular part of physical training. One strategy for reducing the deleterious effects of sit-up training is substituting core strengthening exercises for sit-up training. Recent research has shown that regular performance of core strengthening exercises in lieu of sit-up training may contribute to small, but statistically significant, improvement in sit-up scores when compared with trainees who performed conventional sit-up training [125].

Shoulder Instability

Shoulder dislocation is an injury that is endemic to young athletes and physically active populations [126]. These injuries typically occur among younger males with a very high rate of recurrence. They also result in substantial loss of training time and may require surgical stabilization for optimal outcomes [126]. Among cadets at the US Military Academy, incidence of shoulder dislocation has been reported at 1.69 per 1000 person-years which is considerably higher than the incidence of the general US population [127]. This elevated risk is likely due to factors associated with the strenuous nature of military training. The risk of subsequent instability is a major concern as researchers have shown that up to 67% of the subjects with a history of dislocation will sustain another dislocation within 5 years [126]. For this reason, many military surgeons advocate early surgical intervention in these patients with arthroscopic Bankart repair [128, 129]. However, for a basic trainee, immediate surgical intervention usually necessitates cessation of training for a period of approximately 6–9 months. The decision to recommend surgical intervention is a complicated decision that clinicians face when working with IET trainees as the competing demands of maintaining shoulder stability and favorable long-term outcomes is often in direct conflict with the trainee's desire to complete training without delay.

Clinical Considerations in IET

One of the main difficulties for the clinician managing recruit injuries is the necessity to safely manage recruits with serious injuries while still maximizing training opportunities. With many minor injuries such as muscle strains and minor ligamentous sprains, it is possible for the clinician to restrict the recruit's duties for a few days in order to allow recovery without missing any crucial training events. Severe injuries such as fractures, dislocations, or ligamentous tears often necessitate removing the recruit from training entirely in order to allow time for potential surgical intervention and appropriate rehabilitation. Often, the timing of an injury is a major consideration when determining whether or not a recruit can continue training. For instance, a recruit who dislocates his shoulder near the end of IET may be able to continue training if he has already completed all of the major physical training requirements involving the upper extremity. Upon completion of training, he may be able to complete rehabilitation or surgical intervention as needed. However, a recruit who sustains the same injury early in the training cycle may not have the opportunity to rest the shoulder and remain in training due to the risk of reinjury [126].

Injury Prevention in IET

In the US Army, soldiers who sustain injuries during training that require intensive rehabilitation and lost training time are transferred to the Warrior Transition and Rehabilitation Program (WTRP). The average length of stay for a WTRP soldier from 2001 to 2010 was 93 days, with an average return to duty rate of 70 % [130]. Soldiers diagnosed with FNSIs sometimes require longer rehabilitation times. Talbot reported a 66 % return to duty rate after lengthy rehabilitation (range from 3 to 7 months) with only a 33 % success rate at continuing training [78]. The WTRP is usually commanded by an active duty physical therapist who helps to manage the rehabilitation of injured recruits. Recruits assigned to the WTRP are transferred out of their training units in order to move to a unit, which is more conducive to proper rehabilitation. Recruits assigned to the WTRP are allowed up to 6 months to conduct rehabilitation of their injuries and restore their physical conditioning in order to return to duty. Upon completion of rehabilitation, recruits are returned to their training units to complete training. Recruits who are unable to return to duty after a period of 6 months are reviewed by a panel of medical providers to determine if they will be able to return to duty or possibly to recommend discharge from the military.

While the WTRP is an excellent concept for rehabilitating injured recruits, it presents its own unique set of challenges. First, recruits assigned to the WTRP require supervision by a military chain of command, which requires military manpower. By regulation, the staff of a WTRP unit must consist of at least 1 drill sergeant for

every 15 assigned recruits [131]. Additionally, these injured recruits require living space, dining facilities, and continue to draw active duty pay and benefits while they conduct rehabilitation. Because these recruits continue to draw pay and benefits while they are injured, there is potential for issues associated with secondary gain of being injured. These problems are similar to the issues involved in workman's compensation situations in the civilian population. Those recruits who fail to complete the WTRP program represent a large financial investment that ultimately fails to produce a physically fit active duty service member.

Many programs have been implemented over the past several decades in an attempt to reduce the number and impact of musculoskeletal injuries in the military. Most recently, the Army has implemented the Musculoskeletal Action Team (MAT). The MAT is a team of exercise and fitness experts led by an active duty physical therapist. The MAT works with IET battalions to prevent and manage musculoskeletal injuries. The MAT concept was first implemented in the Army in 2011 and is still undergoing testing to evaluate its effectiveness. The MAT consists of the active duty physical therapist and an active duty physical therapy technician. They lead a team of civilian athletic trainers and strength coaches who work directly with the IET units. The MAT conducts injury prevention programs and also conducts rehabilitation and reconditioning for injured recruits. Ideally, the MAT has 1 athletic trainer and 1 strength coach assigned to each IET battalion, which consists of approximately 800 recruits. Preliminary studies have found decreased injury rates, decreased attrition, and improved physical fitness test scores in units with MAT support [132].

Injury prevention techniques for FNSIs are highly studied due to the severity of complications that occur from undiagnosed injuries. The most important prevention technique for femoral neck stress fractures is active monitoring of soldiers by their training cadre. As soon as a trainee complains of hip pain or is limping after activity, he should be seen by a medical professional to rule out this significant injury. Some successful injury prevention techniques have included reducing running mileage [45], wearing an orthotic in the boot [9], modifying training that requires running and marching [91], and supplementation with calcium and vitamin D [79, 133].

In the Scott et al. study, their primary focus was combining leadership education, leadership enforcement, and injury surveillance [130]. Leadership education included best practice injury prevention principles to include prevention of overtraining, performing agility training, and consuming nutrients to restore energy balance within 1 h following activity. With the help of changes to training in BCT, including limiting corrective action exercises and mandating physical training through Physical Readiness Training (PRT), the overall reduction of FNSIs was the largest from 2009 to 2010. Injury surveillance was also shown to be important but not as significant across all companies.

Injury prevention techniques for pelvic stress fractures include marching speed of approximately 3 mph, height ordered ruck marching, allowing soldiers to walk at their own comfortable stride length, decreasing overall foot time to include running and march time in boots, running intervals instead of mid-distances, and changing running surfaces to softer, more compliant types. With these changes, the Australian

Army's first Recruit Training Battalion was able to decrease the incidence of pelvic stress injuries from 11.2 to 0.6% [91]. The US Army's PRT program also includes hip stability drill exercises to further enforce the strength and endurance of these muscles also promoting prevention.

Recently, certain running gait characteristics have been identified as potentially being associated with greater risk of injury. These include heel striking [134], greater peak hip internal rotation [16], and decreased knee flexion [16, 135]. It is possible that this combination of running characteristics contribute to increased ground reaction forces, which increases the overall risk of injury [16, 135]. Running techniques that emphasize midfoot or forefoot striking patterns may decrease ground reaction forces and improve running mechanics [136–138]. While research has demonstrated that changing running techniques can contribute to decreased ground reaction forces and improved mechanics, evidence is still lacking to determine if these altered running techniques are able to prevent injuries.

Another injury prevention tool that is not highly researched is nutrition. Since military training is usually the most difficult form of exercise, many trainees have had to perform to date, an acute negative energy balance usually occurs along with weight loss. A sustained negative energy balance may negatively affect the muscle's ability to recover from exercise and may result in bone collagen synthesis [139]. Costill et al. showed that muscle glycogen is depleted over 3 days of intense training when a diet of just 40% carbohydrates is consumed [140]. This coupled with the typical training cycle that promotes a lack of food for more than 12 h followed by intense morning exercise would result in sustained depletion of glycogen levels in the leg muscles. As previously mentioned and published in many research articles, lack of general muscular strength, regardless of the underlying factors, will lead to increased risk of stress injury.

Vitamin D and calcium supplementation is a nutritional injury prevention concept that has recently been tested in military recruits. Researchers have found that supplementation 2000 mg calcium and 800 IU vitamin D contributed to a 20% lower incidence of stress fracture in female Navy recruits during basic training [79]. In another study of male and female recruits, Gaffney-Stomberg et al. found that recruits who supplemented their diet with 2000 mg calcium and 1000 IU vitamin D had improved bone mineral density and bone mineral content [133]. While this study did not examine the direct effects on stress fractures, the authors proposed that these improved indicators of bone health may correlate with a decreased risk of bone stress injury.

Because of the tremendous monetary cost associated with injured trainees as well as the public health concern of trainee injuries, the Department of Defense has placed great emphasis on injury prevention efforts [141]. The most preventable cause of trainee injuries is overtraining. However, controlling for overtraining is difficult in IET as there are physical demands which are necessary in order to adequately train military service members. One effort to reduce the impact of physical training injuries is the recent revision to the Army's entire physical training program. Since 2003, the Army has been transitioning to a new exercise program called "Physical Readiness Training (PRT)." In PRT, unit commanders are responsible

for all aspects of physical fitness and the program is designed to provide physical fitness training specifically oriented towards helping service members meet fitness objectives related to their mission [142]. In one trial of PRT in a BCT environment, the risk of overuse injuries was reduced by 52% among female recruits, and by 46% among male recruits [143]. One of the major changes associated with PRT is a reduction in the amount of distance running performed by service members. Previous fitness training models often involved running up to 5 days/week. PRT requires running for not more than 30 min at a time and not more than three sessions per week. The remaining physical fitness training time is devoted to strength and agility training [142]. While this reduction in running has demonstrated a risk reduction in research, overuse injuries continue to plague military service members in IET environments.

Conclusions

Clearly, musculoskeletal injuries are a serious problem in IET trainees. Despite numerous efforts to reduce the frequency and severity of these injuries, musculoskeletal injuries continue to affect thousands of trainees across all branches of service every year. These injuries are responsible for thousands of doctor visits each year and millions of training days lost. The financial cost of these injuries, while substantial, is extremely difficult to quantify due to the multifactorial nature of the problem but are conservatively in excess of \$3 billion annually. Perhaps more importantly, these injuries represent a significant decrease in military readiness and a major public health concern within military populations.

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References

1. Population representation in the military services: Fiscal Year 2011 Summary Report. Office of the Under Secretary of Defense, Personnel and Readiness. <http://prhome.defense.gov/rfm/MPP/ACCESSION%20POLICY/PopRep2011/index.html>. Accessed 25. June 2013.
2. Frequently asked questions about recruiting. 2013. <http://www.usarec.army.mil/support/faqs.htm#costper>. Accessed 13. June 2013.
3. Jones, BH, KG Hauret, Piskator DE. Review of the literature on attrition from the military services 2004;1–105.
4. DeKonig B. Recruit Medicine. Textbooks of military medicine. Washington, DC: Fort Sam Houston, (Tex.: Falls Church, Va.: Office of The Surgeon General, U.S. Army: Borden Institute, Walter Reed Army Medical Center; U.S. Army Medical Dept. Center and School); 2006.

5. National Research Council. Physical fitness and musculoskeletal injury. In: Sackett PR, Mavor AS, Editors. Assessing fitness for military enlistment: physical, medical, and mental health standards. Washington, DC: National Academies Press; 2006. pp. 66–108.
6. 19K10-One Station Unit Training Program of Instruction. 2012. http://www.benning.army.mil/armor/194th/content/PDF/19K_OSUT_POI.pdf. Accessed 30 June 2015.
7. Burr DB, Milgrom C. Musculoskeletal fatigue and stress fractures. Boca Raton: CRC Press; 2001. pp. 1–36.
8. Fitzgerald RH, Kaufer H, Malkani AL. Orthopaedics. St. Louis: Mosby; 2002.
9. Milgrom C, Giladi M, Kashtan J, et al. A prospective study of the effect of a shock-absorbing orthotic device on the incidence of stress fractures in military recruits. *Foot Ankle*. 1985;6:101–4.
10. Chen JH, Liu C, You L, Simmons CA. Boning up on Wolf's law: mechanical regulation of the cells that make and maintain bone. *J Biomech*. 2010;43:108–18.
11. Romani WA, Perrin DH, Dussault RG, Ball DW, Kahler DM. Identification of tibial stress fractures using therapeutic continuous ultrasound. *J Orthop Sports Phys Ther*. 2000;30:444–52.
12. Taylor D, Casolari E, Bignardi C. Predicting stress fractures using a probabilistic model of damage, repair and adaptation. *J Orthop Res*. 2004;22:487–94.
13. Armstrong DW 3rd, Rue JP, Wilckens JH, Frassica FJ. Stress fracture injury in young military men and women. *Bone*. 2004;35(3):806–16.
14. Almeida SA, Williams KM, Shaffer RA, Brodine SK. Epidemiological patterns of musculoskeletal injuries and physical training. *Med Sci Sports Exerc*. 1999;31:1176–82.
15. Kaufman KR, SK Brodine, RA Shaffer, CW Johnson, Cullison TR. The effect of foot structure and range of motion on musculoskeletal overuse injuries. *Am J Sports Med*. 1999;27:585–93.
16. Linenger JM, West LA. Epidemiology of soft tissue/musculoskeletal injury among US Marine recruits undergoing basic training. *Mil Med*. 1992;157:491–3.
17. Brudvig TJ, Gudger TD, Obermeyer L. Stress fractures in 295 trainees: a one-year study of incidence as related to age, sex, and race. *Mil Med*. 1983;148:666–7.
18. Jones BH, Bovee MW, Harris JM III, et al. Intrinsic risk factors for exercise-related injuries among male and female Army trainees. *Am J Sports Med* 1993;21:705–10.
19. Knapik J, Montain SJ, McGraw S, Grier T, Ely M, Jones BH. Stress fracture risk factors in basic combat training. *Int J Sports Med*. 2012;33:940–6.
20. Macleod MA, Houston AS, Sanders I, Anagnostopoulos C. Incidence of trauma related to stress fractures and shin splints in male and female Army recruits: retrospective case study. *BMJ*. 1999;318:29.
21. Mattila VM, Niva M, Kiuru M, Pihlajmaki H. Risk factors for bone stress injuries: a follow-up study of 102,515 person-years. *Med Sci Sports Exerc*. 2007;39:1061–6.
22. Proztzman RR. Physiologic performance of women compared to men. Observations of cadets at the United States Military Academy. *Am J Sports Med*. 1979;7:191–4.
23. Yale J. A statistical analysis of 3,657 consecutive fatigue fractures of the distal lower extremities. *J Am Podiatry Assoc*. 1976;66:739–48.
24. Benseck CK, Kish RN. Lower extremity disorders among men and women in Army basic training and effects of two types of boots. (Technical report Matick TR-83/026). Natick: US Army Natick Research and Development Laboratories; 1983.
25. Bijur PE, Horodyski M, Egerton W, Kurzton M, Lifrak S, Friedman S. Comparison of injury during cadet basic training by gender. *Arch Pediatr Adolesc Med*. 1997;151:456–61.
26. Canham ML, Knapik JJ, Smutek MA. Training, physical performance, and injuries among men and women preparing for occupations in the Army. In: Kumas S, editor. Advances in occupational ergonomics and safety: proceedings of the XIIIth Annual International Occupational Ergonomics and Safety Conference 1998. Washington, DC: IOS Press; 1998. pp. 711–14.
27. Kowal D. Nature and causes of injuries in women resulting from an endurance training program. *Am J Sports Med*. 1980;8:265–9.
28. Protzman RR, Griffiths CC. Comparative stress fracture incidence in males and females in equal training environments. *Athletic Train*. 1977;12:126–30.

29. Reinker L, Ozbourne S. A comparison of male and female orthopaedic pathology in basic training. *Mil Med.* 1979;143:532–6.
30. Glorioso JE, Leadbetter WB. Femoral supracondylar stress fractures. *Phys Sportsmed.* 2002;30:25–8.
31. Otis CL, Drinkwater B, Johnson M, Loucks A, Wilmore J. American College of Sports Medicine position stand. The female athlete triad. *Med Sci Sports Exerc.* 1997;29:i–ix.
32. Gardner LI Jr, Dziados JE, Jones BH, et al. Prevention of lower extremity stress fractures: a controlled trial of shock absorbent insole. *Am J Public Health.* 1988;78:1563–7.
33. Milgrom C, Finestone A, Shlamkovitch N et al. Youth is a risk factor for stress fractures: a study of 783 infantry recruits. *J Bone Joint Surg Br.* 1994;76:20–2.
34. Beck TJ, Ruff CB, Mourtada FA, et al. Dual energy x-ray absorptiometry derived structural geometry for stress fracture prediction in male U.S. Marine Corps recruits. *J Bone Miner Res.* 1996;11:645–53.
35. Giladi M, Milgrom C, Simkin A, et al. Stress fractures and tibial bone width. A risk factor. *J Bone Joint Surg Br.* 1987;69:326–9.
36. Giladi M, Milgrom C, Simkin A, Danon Y. Stress fractures. Identifiable risk factors. *Am J Sports Med.* 1991;19:647–52.
37. Milgrom C, Finestone A, Sharkey N. Metatarsal strains are sufficient to cause fatigue fracture during cyclic overloading. *Foot Ankle Int.* 2002;23:230–5.
38. Pate RR, Wang CY, Dowda M, Farrell SW, O'Neill JR. Cardiorespiratory fitness levels among US youth 12–19 years of age: findings from 1999–2002 national health and nutrition examination survey. *Arch Pediatr Adolesc Med.* 2006;160(10):1005–12.
39. Knapik JJ, Sharp MA, Dakjy S, Jones SB, Hauret KG, Jones BH. Temporal changes in the physical fitness of US Army recruits. *Sports Med.* 2006;36(7):613–34.
40. Molloy JM, Feltwell DN, Scott SJ, Neiburh DW. Physical training injuries and interventions for military recruits. *Mil Med.* 2012;177(5):553–8.
41. Beck TJ, Ruff CB, Shaffer RA, et al. Stress fracture in military recruits: gender differences in muscle and bone susceptibility factors. *Bone.* 2000;27:437–44.
42. Bennell KL, Malcolm SA, Thomas SA, et al. Risk factors for stress fractures in track and field athletes. A twelve-month prospective study. *Am J Sports Med.* 1996;24:810–8.
43. Gefen A. Biomechanical analysis of fatigue-related foot injury mechanisms in athletes and recruits during intensive marching. *Med Boil Eng Comput.* 2002;40:302–10.
44. Hoffman JR, Chapnik L, Shamis A, Givon U, Davidson B. The effect of leg strength on the incidence of lower extremity overuse injuries during military training. *Mil Med.* 1999;164:153–6.
45. Jones BH, Knapik JJ. Physical training and exercise-related injuries. Surveillance, research and injury prevention in military populations. *Sports Med.* 1999;27:111–25.
46. Milgrom C, Simkin A, Eldad A, Nyska M, Finestone A. Using bone's adaptation ability to lower the incidence of stress fractures. *Am J Sports Med.* 2000;28:245–51.
47. Cootes T, Taylor C, Cooper D, Graham J. Active shape models-their training and application. *Comput Vis Image Underst.* 1995;61:38–59.
48. Flute M, Lavallee S. Building a complete surface model from sparse data using statistical shape models. *Proceedings of the Medical Image Computing and Computer-Assisted Intervention-MIC-CAI'98, First International Conference.* New York: Springer; 1998. (ISBN: 3-540-65136-5). pp. 879–87.
49. Moran DS, Israeli E, Evans RK, Yanovich R, Constantini N, Shabshin N, Merkel D, Luria O, Erlich T, Laor A, Finestone AS. Prediction model for stress fracture in young female recruits during basic training. *Med Sci Sports Exerc.* 2008;40:636–44.
50. Moran DS, Finestone AS, Arbel Y, Shabshin M, Laor A. A simplified model to predict stress fracture in young elite combat recruits. *J Strength Cond Res.* 2012;26:2585–92.
51. Rajamani L, Joshi SC, Styner M. Bone model morphing for enhanced visualization. In: *IEEE Symposium on Biomechanical Imaging.* ISBN: 0-7803-8388-5; New York: IEEE; 2004. pp. 1255–58.
52. Brunet ME, Cook SD, Brinker MR, et al. A survey of running injuries in 1505 competitive and recreational runners. *J Sports Med Phys Fitness.* 1990;30:307–15.

53. Yanovich R, Merkel D, Israeli E, Evans RK, Erlich T, Moran DS. Anemia, iron deficiency, and stress fractures in female combatants during 16 months. *J Strength and Cond Res.* 2011;25:3412–21.
54. Rome K, Handoll HG, Ashford RL. Interventions for preventing and treating stress fractures and stress reactions of bone of the lower limbs in young adults. *Cochrane Database of Syst Rev.* 2005;2:1–49.
55. Milgrom C, Finestone A, Shlamkovitch N et al. Anterior knee pain caused by overactivity: a long term prospective follup. *Clin Orthop Relat Res.* 1996;331:256–60.
56. Milgrom C, Burr D, Fyhrrie D, et al. A comparison of the effect of shoes on human tibial axial strains recorded during dynamic loading. *Foot Ankle Int.* 1998;19:85–90.
57. Bennell K, Brukner P. Preventing and managing stress fractures in athletes. *Phys Ther Sport.* 2005;6:171–80.
58. Brukner P, Bennell K. Stress fractures in female athletes. Diagnosis, management and rehabilitation. *Sports Med.* 1997;24:419–29.
59. Devereaux MD, Parr GR, Lachmann SM, Page-Thomas P, Hazleman BL. The diagnosis of stress fractures in athletes. *JAMA.* 1984;252:531–3.
60. Frederickson M, Wun C. Differential diagnosis of leg pain in the athlete. *J Am Podiatr Med Assoc.* 2003;93:321–4.
61. Frederickson M, Bergman AG, Hoffman KL, Dillingham MS. Tibial stress reaction in runners. Correlation of clinical symptoms and scintigraphy with a new magnetic resonance imaging grading system. *Am J Sports Med.* 1995;23:472–81.
62. Matheson GO, Clement DB, McKenzie DC, et al. Scintigraphic uptake of ^{99m}Tc at non-painful sites in athletes with stress fractures. *Sports Med.* 1987;4:65–75.
63. Moss A, Mowat AG. Ultrasonic assessment of stress fractures. *Br Med J (Clin Res Ed).* 1983;286:1479–80.
64. Reeder MT, Dick BH, Atkins JK, Pribis AB, Martinez JM. Stress fractures. Current concepts of diagnosis and treatment. *Sports Med.* 1996;22:198–212.
65. Sterling JC, Edelstein DW, Calvo RD, Webb R 2nd. Stress fractures in the athlete. Diagnosis and management. *Sports Med.* 1992;14:336–46.
66. Strauch WB, Slomiany WP. Evaluating shin pain in active patients. *J Musculoskelet Med.* 2008;25:138–48.
67. Touloupoulos S, Hershman EB. Lower leg pain. Diagnosis and treatment of compartment syndromes and other pain syndromes of the leg. *Sports Med.* 1999;27:193–204.
68. Wen DY, Propeck T, Singh A. Femoral neck stress injury with negative bone scan. *J Am Board Fam Med.* 2003;16:170–4.
69. Romani WA, Gieck JH, Perrin DH, Saliba EN, Kahler DM. Mechanics and management of stress fractures in physically active persons. *J Athl Train.* 2002;37:306–14.
70. Wilcox JR, Moniot AL, Green JP. Bone scanning in the evaluation of exercise related stress injuries. *Radiology.* 1977;123:699–703.
71. Edelman B. “Hot” bone scans par for the course. *Orthop Today* 1993;13:1–21.
72. Scully TJ, Griffith JC, Jones B, et al. Bone scans yield a high incidence of false positive diagnoses of stress fractures. (Abstract). Presented at the American Academy of Orthopaedic Surgeons 1993 Annual Meeting, San Francisco, California; Feb 18–23, 1993.
73. Ardent EA, Griffiths HJ. The use of MR imaging in the assessment and clinical management of stress reactions of bone in high-performance athletes. *Clin Sports Med.* 1997;16:291–306.
74. Knapp TP, Garrett WE. Stress fractures: general concepts. *Clin Sports Med.* 1997;16:339–56.
75. McFarland EG, Giangarra C. Sacral stress fractures in athletes. *Clin Orthop Relat Res.* 1996;329:240–3.
76. Schneider AG, Sullivan SJ, Hendrick PA, Hones B, McMaster AR, Sugden BA, Tomlinson C. The ability of clinical tests to diagnose stress fractures: a systematic review and meta-analysis. *J Orthop Sports Phys Ther.* 2012;42:760–71.
77. Lesho EP. Can tuning forks replace bone scans for identification of tibial stress fractures? *Mil Med.* 1997;162:802–3.

78. Talbot JC, Cox G, Townend M, Langham M, Parker PJ. Femoral neck stress fractures in military personnel—a case series. *J R Army Med Corps*. 2008;154(1):47–50.
79. Lappe J, Cullen D, Haynakkzi G, Recker R, Ahlf R, Thompson K. Calcium and vitamin D supplementation decreases incidence of stress fractures in female Navy recruits. *J Bone Miner Res*. 2008;23(5):741–9.
80. Pihlajamäki HK, Ruohola JP, Kiura MJ, Visuri TI. Displaced femoral neck fatigue fractures in military recruits. *J Bone Joint Surg Am*. 2006;88:1989–97.
81. Jones BH, Harris JM, Vinh TN, et al. Exercise-induced stress fractures and stress reactions of bone: epidemiology, etiology and classification. *Exerc Sports Sci Rev*. 1989;17:379–422.
82. Ross RA, Allsopp A. Stress fractures in Royal Marine recruits. *Mil Med*. 2002;167:560.
83. Clough T. Case report femoral neck stress fracture: the importance of clinical suspicion and early review. *Br J Sports Med*. 2002;36:308–9.
84. Boden S, Labropoulos P, Saunders R. Hip fractures in young patients: is this early osteoporosis? *Calcif Tissue Int*. 1990;46:65–72.
85. Hajek BS. Stress fractures of the femoral neck in joggers. *Am J Sports Med*. 1982;10:112–6.
86. Heath J. Athletic women, amenorrhea and skeletal integrity. *Ann Intern Med*. 1985;102:258–259.
87. Muldoon MP, Padgett DE, Sweet DE et al. Femoral neck stress fractures and metabolic bone disease. *J Orthop Trauma*. 2001;15(3):181–5.
88. Perloff JJ, McDermott MT, Perloff FA, et al. Reduced bone mineral content is a risk factor for hip fractures. *Orthop Rev*. 1991;20:690–7.
89. Ville MM, Niva M, Kiuru M, Pihlajamäki H. Risk factors for bone stress injuries: a follow-up study of 102,515 person-years. *Med Sci Sports Exerc*. 2007;39:1061–6.
90. Weistroffer JK, Muldoon MP, Duncan DD, Fletcher EH, Padgett DE. Femoral neck stress fractures: outcome analysis at minimum five-year follow-up. *J Orthop Trauma*. 2003;17:334–7.
91. Pope RP, Herbert RD, Kirwan JD. Effects of flexibility and stretching on injury risk in Army recruits. *Aust J Physiother*. 1998;44:165–72.
92. Johnson AW, Weiss CB Jr, Wheeler DL. Stress fractures of the femoral shaft in athletes—more common than expected. A new clinical test. *Am J Sports Med*. 1994;22:248–56.
93. Finestone A, Milgrom C, Wolf O, Petrov K, Evans R, Moran D. Epidemiology of metatarsal stress fractures versus tibial and femoral stress fractures during elite training. *Foot Ankle Int*. 2011;32:16–20.
94. Boden BP, Speer KP. Femoral stress fractures. *Clin Sports Med*. 1997;16:307–17.
95. Milgrom C, Chisin R, Margulies J, et al. Stress fractures of the medial femoral condyle. *J Trauma*. 1986;26:199–200.
96. Gaeta M, Minutoli F, Scribano E, et al. CT and MR imaging findings in athletes with early tibial stress injuries: comparison with bone scintigraphy findings and emphasis on cortical abnormalities. *Radiology*. 2005;235:553–61.
97. Goldberg B, Pecora C. Stress fractures: a risk of increased training in freshman. *Physician Sportsmed*. 1994;22:68–78.
98. Hulkko A, Orava S. Stress fractures in athletes. *Int J Sports Med*. 1987;8:221–6.
99. Finestone A, Shlamkovitch M, Eldad A, Wosk J, Laor A, Danon YL, Milgrom C. Risk factors for stress fractures among Israeli infantry recruits. *Mil Med*. 1991;156:528–30.
100. Givon U, Friedman E, Reiner A, Vered I, Finestone A, Shemer J. Stress fractures in the Israeli defense forces from 1995 to 1996. *Clin Orthop Relat Res*. 2000;373:227–32.
101. Matheson GO, Clement DB, McKenzie DC, Taunton JE, Lloyd-Smith DR, MacIntyre JG. Stress fractures in athletes. A study of 320 cases. *Am J Sports Med*. 1987;15:46–58.
102. Batt ME, Ugalde V, Anderson MW, Shelton DK. A prospective controlled study of diagnostic imaging for acute shin splints. *Med Sci Sports Exerc*. 1998;30:1564–71.
103. Hallel T, Amit S, Segal D. Fatigue fractures of tibial and femoral shaft in soldiers. *Clin Orthop Relat Res*. 1976;118:35–43.
104. Orava S, Hulkko A. Delayed unions and nonunions of stress fractures in athletes. *Am J Sports Med*. 1988;16:378–82.

105. Ruohola, JS, Kiuru MJ, Pihlajamaki HK. Fatigue bone injuries causing anterior lower leg pain. *Clin Orthop Relat Res.* 2006;44:216–23.
106. Sullivan D, Warren RF, Pavlov H, Kelman G. Stress fractures in 51 runners. *Clin Orthop Relat Res.* 1984;187:188–92.
107. Dutton J, Bromhead SE, Speed CA, Menzies AR, Peters AM. Clinical value of grading the scintigraphic appearances of tibial stress fractures in military recruits. *Clin Nucl Med.* 2002;27:18–21.
108. Montgomery LC, Nelson FR, Norton JP et al. Orthopedic history and examination in the etiology of overuse injuries. *Med Sci Sports Exerc.* 1989;21:237–43.
109. Finestone A, Milgrom C. How stress fracture incidence was lowered in the Israeli Army: a 25-yr struggle. *Med Sci Sports Exerc.* 2008;40:S623–9.
110. Breithaupt J. Zur pathologie des menschlichen fuses. *Med Ztg Berlin.* 1885;24:169–71, 175–7.
111. Duran-Stanton AM. March fractures on a female military recruit. *Mil Med.* 2011;176:53–5.
112. Greaney RB, Gerber FH, Laughlin RL, Kmet JP, Metz CD, Kilcheski TS, Rao BR, Silverman ED. Distribution and natural history of stress fractures in US Marine recruits. *Radiology.* 1983;146:339–46.
113. Spitz DJ, Newberg AH. Imaging of stress fractures in the athlete. *Radiol Clin North Am.* 2002;40:313–31.
114. Weber JM, Vidt LG, Gehl RS, Montgomery T. Calcaneal stress fractures. *Clin Podiatr Med Surg N Am.* 2005;22:45–54.
115. Hopson CN, Perry DR. Stress fractures of the calcaneus in women Marine recruits. *Clin Orthop Relat Res.* 1977;128:159–62.
116. Hullinger CW. Insufficiency fracture of the calcaneus similar to march fracture of the metatarsal. *J Bone Joint Surg Am.* 1944;26:751–7.
117. Giladi M, Alcalay J. Stress fracture of the calcaneus-still an enigma in the Israeli Army. *JAMA.* 1984;252:3128–9.
118. Hershman EB, Mailly T. Stress fractures. *Clin Sports Med.* 1990;9:183–214.
119. Sormaala MJ, Niva MH, Kiuru MJ, Mattila VM, Pihlajamaki HK. Stress injuries of the calcaneus detected with magnetic resonance imaging in military recruits. *J Bone Joint Surg.* 2006;88:2237–42.
120. Rupani HD, Holder LE, Espinola DA, Engin SI. Three-phase radionuclide bone imaging in sports medicine. *Radiology.* 1985;156:187–96.
121. Umans H, Pavlov H. Insufficiency fracture of the talus. Diagnosis with MR imaging. *Radiology.* 1995;197:439–42.
122. Boling MC, Padua DA, Marshall SW, et al. A prospective investigation of biomechanical risk factors for patellofemoral pain syndrome. The joint undertaking to monitor and prevent ACL injury (JUMP-ACL) cohort. *Am J Sports Med.* 2009;37(11):2108–16.
123. O'Connor FG, Marlowe SS. Low back pain in military basic trainees. *Spine.* 1993;18(10):1351–4.
124. Rodríguez-Soto AE, Jaworski R, Jensen A, et al. Effect of load carriage on lumbar spine kinematics. *Spine.* 2013;38(13):E783–91.
125. Childs JD, Teyhen DS, Benedict TM, et al. Effects of sit-up training versus core stabilization exercises on sit-up performance. *Med Sci Sports Exerc.* 2009;41(11):2072–83.
126. Cameron KL. History of shoulder instability and subsequent injury during four years of follow-up. *J Bone Joint Surg Am.* 2013;95(5):439–45.
127. Owens, BD, Dawson L, Burks R, et al. Incidence of shoulder dislocation in the United States military: demographic considerations from a high-risk population. *J Bone Joint Surg Am.* 2009;91(4):791–6.
128. Bottoni CR, Arciero RA. “Arthroscopic repair of primary anterior dislocations of the shoulder.” *Tech Shoulder Elbow Surg.* 2001;2(1):2–16.
129. Owens, BD, DeBerardino TM, Nelson BJ, et al. Long-term follow-up of acute arthroscopic Bankart repair for initial anterior shoulder dislocations in young athletes. *Am J Sports Med.* 2009;37(4):669–73.

130. Scott SJ, Feltwell DN, Knapik JJ, Barkley CB, Hauret KG, Bullock SH, Evans RK. A multiple intervention strategy for reducing femoral neck stress injuries and other serious overuse injuries in U.S. Army Basic Combat Training. *Mil Med.* 2012;9:1081–9.
131. TRADOC Regulation 350-6: Enlisted initial entry training policies and administration. Fort Monroe, VA: Department of the Army Headquarters, United States Army Training and Doctrine Command, 2007. <http://www.tradoc.army.mil/tpubs/regs/tr350-6.pdf>. Accessed 30 June 2015.
132. Knapik JJ, Graham B, Steelman R. The effectiveness of athletic trainers & musculoskeletal action teams in reducing injuries and attrition and enhancing physical fitness in IET. US Army Institute of Public Health, Aberdeen Proving Ground, MD, Aug 21, 2012.
133. Gaffney-Stomberg E, Lutz LJ, Rood JC, Cable SJ, Pasiakos SM, Young AG, McClung JP. Calcium and vitamin D supplementations maintains parathyroid hormone and improves bone density during initial military training: a randomized, double-blind, placebo controlled trial. *Bone.* 2010;8(2):46–56.
134. Daoud AI, Geissler GJ, Wang F, Saretsky J, Daoud YA. Foot strike and injury rates in endurance runners: a retrospective study. *Med Sci Sports Exerc.* 2012;44(7):1325–34.
135. Milner CE, Hamill J, Davis I. Are knee mechanics during early stance related to tibial stress fracture in runners? *Clin Biomech.* 2007;22(6):697–703.
136. Crowell HP, Davis IS. Gait retraining to reduce lower extremity loading in runners. *Clin Biomech.* 2007;26(1):78–83.
137. Goss DL, Gross MT. A review of mechanics and injury trends among various running styles. *US Army Med Dep J.* 2012; Jul-Sep: 62–71.
138. Goss DL, Gross MT. A comparison of negative joint work and vertical ground reaction force loading rates in Chi runners and rearfoot-striking runners. *J Orthop Sports Phys Ther.* 2013;43(10):685–92.
139. Zanker CL, Swaine IL. Responses of bone turnover markers to repeated endurance running in humans under conditions of energy balance or energy restriction. *Eur J Appl Physiol.* 2000;83:434–40.
140. Costill DL, Bowers R, Branam G, Sparks K. Muscle glycogen utilization during prolonged exercise on successive days. *J Appl Physiol.* 1971;31:834–8.
141. Rumsfeld DH. Memorandum. Office of the Secretary of Defense. Reducing preventable accidents. 19 May 2003.
142. FM 7-22 Army Physical Readiness Training. Washington, DC: Headquarters, Department of the Army; 2012.
143. Knapik JJ, Hauret KG, Arnold S, et al. Injury and fitness outcomes during implementation of physical readiness training. *Int J Sports Med.* 2003;24:372–38.

Chapter 6

Disability Associated with Musculoskeletal Injuries

Chad A. Krueger and James R. Ficke

Introduction

Musculoskeletal-related injuries and disabling conditions represent the fastest-growing subset of military disability claims over the last 30 years. From 1981 to 2005, the number of disabling conditions related to the musculoskeletal system increased from 70/100,000 persons to 950/100,000 persons for those exiting the military [1]. While there are many factors, such as an increase in combat missions or an increasing recognition of disabling conditions, that may account for this increase, recent analysis has shown that the almost 12-fold increase in musculoskeletal disability claims is coming largely from young, enlisted servicemen and servicewomen with lower levels of education [1]. These disabling conditions require a disproportionately large amount of resources to care for [2–4], and it is imperative to have a basic understanding of these ailments to develop and implement effective injury prevention strategies and to optimize the care provided to these patients [5]. This chapter discusses the burden of disability associated with some of the more common musculoskeletal injuries and conditions seen within the military.

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89

Upper Extremity

Shoulder Instability and Superior Labrum Anterior and Posterior Tears

In an evaluation of 275 consecutive Navy patients for shoulder complaints, Provencher et al. [6] found that those patients who underwent surgery to correct their pathology (instability, rotator cuff, or labral tear) had outcome scores that were lower than those of patients who were treated nonoperatively. This suggests that patients with shoulder injuries sustained on active duty that require surgical treatment may continue to have persistent pain and decreased function after repair. Obviously, those patients who were treated nonoperatively likely had less serious shoulder conditions than those who underwent operative treatment, but the finding remains important when counseling patients on their expected prognosis. Furthermore, their study found that the outcome scores were similar across the different shoulder conditions (superior labrum anterior and posterior tears, rotator cuff tears, and shoulder instability) evaluated [6]. These findings suggest that it may simply be the fact that the shoulder is injured that determines the outcome as much as it is the type of injury or method of fixation.

A similar study looked at 179 active duty Navy patients who were prospectively evaluated for type 2 superior labrum anterior and posterior (SLAP) tears and followed for close to 4 years. This study showed an improvement in the mean Single Assessment Numeric Evaluation (SANE) score from 50 to 85 and the mean American Shoulder and Elbow Surgeons Standardized Shoulder Assessment (ASES) score from 65 to 88 after repair. Considering that any score above 90 is considered a “normal” shoulder, these results indicate that type 2 SLAP tears can be reliably fixed, and most patients can return to their baseline activities [7].

When specifically looking at shoulder instability, the age at which the patient first dislocates his shoulder seems to matter more than anything else [8]. Older patients who undergo surgical treatment for their instability with a Bankart procedure are less likely to have recurrent instability than a younger person. In fact, one study found that there is a 7% decrease in dislocation rate for each year older a patient is when they undergo the Bankart repair [8]. In an analysis of 3854 military personnel who underwent a Bankart repair, 5% underwent revision surgery for instability, and 8.8% were medically discharged with complaints of shoulder instability at 2–7 years of follow-up [9]. When extrapolating literature looking at the return to sports from the civilian literature, around 90% of athletes can expect to return to their previous level of activity around 6 months following surgery with an average increase of 20 points on their ASES [8, 10, 11]. However, it should be noted that a history of multiple dislocations and trying to return to the previous level of activity without taking enough time off for rehabilitation or surgery decreases the likelihood of a patient making a full recovery [11, 12]. In terms of chronic disability after surgical repair, there appears to be a relatively low

level of osteoarthritis (OA) that develops after either arthroscopic or open Bankart repairs; however, this may be dependent on the degree of glenoid and/or humeral head bone loss [13]. In more severe cases of instability where bone loss is present and a Latarjet procedure is indicated, the outcomes also appear to be promising. In an analysis of 68 Latarjet procedures in young adults, the mean Rowe score increased almost 38 points during the 20-year study period [14]. Patients who are undergoing a Latarjet procedure for instability, however, are at a higher risk of developing OA compared to those patients who are able to be treated with a Bankart procedure alone [15].

Rotator Cuff

There are not any military-specific studies that examine outcomes after rotator cuff injuries. However, Provencher et al. showed that rotator cuff repairs fared no better or worse than SLAP tears or cases of shoulder instability in terms of functional outcome scores after surgery [6].

A review of 78 workers' compensation patients who underwent arthroscopic rotator cuff repair of full-thickness rotator cuff repairs showed that almost 90 % of the patients were able to return to their preoperative level of work at an average of 7.6 months [16]. These findings suggest that active duty personnel who have not returned to full duty at a year may be unlikely to do so with further recovery. Recovery may also depend on the physical demands of each patient's job as patients who do lighter-duty work returned to work at a higher rate than those who did heavy work [16]. Vocation aside, the vast majority of patients who undergo a repair for a rotator cuff injury have a good outcome at 1 and 2 years after their injury [17, 18]. There has been little to no work assessing return to duty after elbow or wrist injury.

Upper Extremity Amputations

Upper extremity amputations have dramatic affects on patient disability [19, 20]. Despite advances in prosthetic and rehabilitation options [21], a recent study comparing upper extremity amputees from the Vietnam war with upper extremity amputees from the Operation Iraqi Freedom/Operation Enduring Freedom (OIF/OEF) conflicts suggests that there is little change in patient satisfaction between groups [22]. In addition, research suggests that, as a whole, upper extremity amputees have significantly higher disability ratings and are significantly less likely to be found fit for duty compared to lower extremity amputees [23].

One reason that prosthetic advances may not be having a greater impact on patient satisfaction is that many upper extremity amputees tend to avoid using their prostheses. Recent data suggest that 30–50 % of all upper extremity amputees, regardless of prostheses type, report minimal daily usage of their prosthetic limb [22].

Additionally, only 50 % of OIF/OEF upper extremity amputees who have a myoelectric device use it daily, whereas 68 % of OIF/OEF upper extremity amputees use their mechanical device daily [22]. Less frequent prosthetic usage may be part of the reason why patients who have a more distal upper extremity amputation report increased life satisfaction than patients with proximal amputations [22] as they may be less reliant on the prosthesis for function.

For upper extremity amputations taking place at least 90 days after the date of injury, it is important to note that performing a late upper extremity amputation may not completely eliminate some of the associated problems with the salvaged limb. One study of these patients showed that half of the patients who underwent late upper extremity amputation in part because of the heterotopic ossification and neurogenic pain in their limb had recurrence of those issues postoperatively [24].

Upper Extremity Limb Salvage

There is very little research assessing outcomes or associated disabilities with upper extremity limb salvage. There is strong historic dogma that even a minimally functional upper extremity is better than no upper extremity at all [19, 20, 24]. While there may be some truth to this line of thinking [25], complications, such as heterotopic ossification, neuroma formation, and infection, are common in this patient cohort [24, 26].

Spine

Disorders of the spine are quite common within the military, especially in the combat environment [5, 27, 28]. Yet, the long-term outcome and disability of the military personnel who sustain these injuries remains unknown. Previous civilian studies have found that polytrauma patients who sustain thoracolumbar fractures associated with neurologic injury tend to have poor recoveries in terms of physical function [29]. While it can be assumed that the 17 % of active duty personnel who sustained a spinal cord injury from combat [28] have a similarly poor outcome and continued disability from their injury, this has not been longitudinally reported.

Noncombat-related spinal injuries within the military are also common causes of disability. One cross-sectional survey of military office workers in the Belgium military found that 51 % of the military force experience regular neck pain throughout the year, and 63 % of those patients reporting this pain state that it interferes with their life [30].

When examining lumbar degenerative disk disease within the military, one study found that older, female, enlisted patients were more likely to suffer from degenerative disk disease than younger patients [27]. While there are no published data on the disability from degenerative disk disease within the US military, rates are

likely high, giving the incidence and prevalence of low back pain in this population. Studies have also shown that chronic pain or function at baseline predicts a worse outcome for those patients who are required to miss work or seek treatment at an emergency department for back pain [31, 32].

Lower Extremity

Cartilage Injuries

There has only been one study examining the outcomes and disabilities associated with cartilage preservation and restoration knee surgery within the military. In a review of 38 consecutive osteochondral autografts at a single institution, 42% were unable to return to duty in any form because of continued disability related to their operative knee. Of the 29% of patients returned to full duty, only two stated that they were symptom free and could continue unrestricted activity [33]. Although there are many possible confounders that could affect these results, this study shows that cartilage defects within the knee prevent nearly all military personnel from returning to their pre-injury level of function.

These military-specific findings are in stark contrast to published reports for college and professional athletes. Those studies have found that 65–79% of athletes reached their pre-injury level of sports within a year of surgical treatment of the cartilage lesion, and close to 90% were able to return in a limited capacity [34, 35]. Age greater than 25 and preoperative symptoms lasting longer than 12 months negatively affected an athlete's ability to return to sports [34]. It is unclear why these results have not been replicated within the military.

Anterior Cruciate Ligament Injury

There is no literature that examines the short- or long-term disabilities encountered by active duty personnel who sustain anterior cruciate ligament (ACL) injuries, and the civilian literature looking at such outcomes vary widely [36]. However, it may be possible to extrapolate earlier studies examining an athlete's ability to return to play to a service member's ability to return to duty. Although between 60 and 80% of high school and college athletes return to their previous level of competition following ACL reconstruction [37, 38], only 40% of athletes thought they returned to their previous level of performance after ACL reconstruction [38]. As many as 85% of patients who sustain an ACL injury go on to experience eventual posttraumatic osteoarthritis (PTOA) of the injured knee, and one study suggested that the ACL rupture was equivalent to adding 30 years of degenerative wear to the native knee [39]. While these estimates may be high, they indicate that even if service members are able to return to duty after an ACL injury, it is likely that their injured knee will cause them some type of late disability.

Meniscus

Interestingly enough, it appears that the status of the menisci at the time of ACL injury is the main determinant of developing PTOA [39]. Service members injure their menisci at a rate that is almost ten times as high as civilian population [40, 41]. Yet, there are no studies specifically looking at the outcomes or persistent disability these injuries cause service members. While the civilian literature details outcomes that are often good or excellent, it is difficult to translate these results to an active duty population secondary to the unique physical demands of military personnel. Meniscus transplantation is an intriguing treatment option for young, active military personnel who have severe meniscal injuries, but the long-term outcome of this procedure is not established [40].

Lower Extremity Amputations

Lower extremity amputation is the fifth most common unfitting condition for service members who were injured in battle and the injury that has the greatest disability impact when accounting for the percent of disability for each injury and the frequency with which each disability appeared [5]. These facts speak to the short- and long-term debility associated with these injuries for service members.

According to the military-specific Military Extremity Trauma Amputation/Limb Salvage (METALS) study, amputees have improved patient-reported outcome scores compared to limb salvage patients who sustained similar injuries [42]. However, these patients sustained their injury and amputation prior to the development of more focused limb salvage rehabilitation and the Intrepid Dynamic Exoskeletal Orthosis (IDEO). The METALS conclusions suggest that focused rehabilitation may be the largest determinant of outcomes, in the limb-loss cohort, leading to their improved outcome [43].

One study found no difference in SF-36 scores or Prosthesis Evaluation Questionnaire subsections between transtibial amputees undergoing modified-Ertl and modified-Burgess transtibial amputations. However, those amputees who underwent a modified Ertl amputation were significantly more likely to require a revision amputation [44]. For those service members who undergo a hip disarticulation or transpelvic amputation, they are likely to require lifelong assistance and will do better in mental outcome scores than physical outcome scores [45].

When evaluating the ability of amputees to return to duty and be deployed, amputees have been found to have a return-to-duty rate of 12.5% after type III tibial fracture [46]. This rate is lower than the 20.5% rate of return to duty for those limb salvage patients sustaining the same injury and the 51% of those service members undergoing limb salvage for a lower extremity injury who participated in the return-to-run (RTR) pathway using an IDEO [47]. Only 5% of all combat-related amputees deploy after their amputation. However, members of the Special Forces deploy at a 48% rate after amputation. This increased rate likely stems from them

having a greater psychosocial support and increased incentive compared to the general military population [48].

Lower Extremity Limb Salvage

Lower Extremity Assessment Project (LEAP) data concluded no differences between limb salvage and amputations. The METALS study found worse outcomes with limb salvage and also lower return to vigorous activity and significantly higher depression screening [49, 50]. However, in a prospective study of limb salvage patients who were able to use IDEO and RTR pathway, there was significant improvement in their measured physical abilities, pain, and self-assessment tests at the 4- and 8-week evaluation points. Just as importantly, 41 of the 50 patients who were initially considering amputation at the start of the study for their injured lower extremity favored limb salvage after 8 weeks of training and rehabilitation with IDEO and RTR [49].

Still, between 10 and 15% of those patients who attempt lower extremity limb salvage go on to seek a late amputation [51, 52]. Additionally, research has shown that those service members who sustain complications related to their salvaged tibia and hindfoot injuries are significantly less likely to return to duty than those who did not [53, 54]. Lastly, PTOA, the most common disabling condition for those service members who are injured in battle [5], is thought to be quite prevalent among the limb salvage population.

Osteoarthritis

Osteoarthritis (OA) is a chronic degenerative disease that impacts the articular cartilage, bone, and surrounding soft tissues in the affected joint. It is estimated that more than 27 million adults in the USA are affected by this debilitating condition [55]. Known risk factors for OA include female sex, obesity, history of joint injury, and engaging in occupations that require a significant amount of repetitive bending, squatting, kneeling, and lifting [6, 56–65]. While OA is typically thought to be a disease that affects individuals later in life, recent studies suggest that OA can affect individuals in their third and fourth decade of life, particularly in the presence of these known risk factors [59, 66]. OA has been a leading cause of disability and medical discharge in the US military for over a decade [67].

Military service members are regularly exposed to many of the known risk factors for OA described above. Military service members have been shown to be at increased risk to acute traumatic joint injury due to the physical training requirements and the nature of their work [41, 68–71]. Furthermore, the physical training and occupational demands placed upon military service members require a significant amount of repetitive bending, squatting, kneeling, and lifting. Finally, while most

military service members are not obese, many are required to endure heavy equipment loads during training and the performance of their occupational tasks. This may produce similar outcomes in terms of joint damage due to excessive loading that have been observed in obese individuals.

Emerging data suggest that the incidence of OA among active duty US military personnel is significantly higher when compared to the general population [72, 73]. Cameron et al. [73] conducted a retrospective cohort study using data from the Defense Medical Surveillance System to examine the incidence rate and burden of OA among military service members. The authors hypothesized that the rates of degenerative joint disease among active duty military personnel would be significantly higher when compared to the general population. The authors observed that the incidence rate for OA was significantly higher in every age group among military service members when compared to the general population, and that the disparity between military service members and the general population increased with increasing age. While the authors were unable to link the increased incidence rate of OA in this study to a history of prior joint injury or the other risk factors noted above, they speculated that the increased incidence rates observed in the military population were likely a function of the high rates of joint injury and the cumulative stress associated with the physical demands associated with years of military service.

In a separate study, Scher et al. [72] examined the incidence of hip OA among active duty military service members. The overall incidence rate for males was 35 cases per 100,000 person-years, with rates ranging from 32 cases per 100,000 person-years among males to 54 cases per 100,000 person-years among females. While they observed lower incidence rates for hip OA than previously reported in the literature, this is likely because the majority of published studies have focused on the incidence of OA in much older study populations. When the data presented by Scher et al. [72] are compared with sex- and age-stratified data from the general population [57], the incidence rates for OA are 4.76–6.30 times as high in males and 18.32 times as high in female military service members on active duty. The observed incidence rates for hip OA in this relatively young and healthy population are disconcerting, and combined with the overall rates for OA in comparison to the general population raise concerns about the burden of OA in load-bearing joints following years of military service.

In addition to the higher incidence rates for any OA diagnosis and hip OA observed in military populations, PTOA has been noted as the primary source of disability in military service members injured in battle [74]. Rivera et al. [74] noted that fractures and arthrotomies resulting from explosive devices caused 75% of the PTOA conditions observed following battle wounds. High rates of PTOA were particularly noted following injury to the weight-bearing joints in the lower extremity including the knee (100%) and ankle (91%). High rates of PTOA were also observed in the elbow (96%) in the upper extremity. The most alarming finding reported by Rivera and colleagues was that the average time from injury through PTOA diagnosis, classification as a disabling condition, and documentation in the medical record was 19 (± 10) months. While PTOA has

been observed to advance at increased rates (e.g., within 10 years of injury) in the general population [59], the rate of progression to PTOA following combat-related injuries appears to be 5–10 times faster in military service members.

Concomitant Mental Health Conditions

More than 50 % of both amputees and limb salvage patients alike will be diagnosed with a mental health condition within their first year of treatment [75]. These conditions appear likely to persist, too, as more than 75 % of Veterans screened in one survey endorsed increased irritability, sleep disturbance, forgetfulness, and anxiety many years after their tour of duty [76]. Such mental health conditions can have a profound effect on both short- and long-term disability as patients with psychological distress are known to have inferior outcome scores when compared to similar cohorts without the psychological distress [77].

Traumatic Brain Injury

One of the more recent disabilities to be noted from the OIF/OEF/Operation New Dawn conflicts is that of traumatic brain injury (TBI). It has been estimated that 10–25 % of service members returning from deployment have at least mild TBI, a rate that seems consistent among multiple injury patterns [75, 78, 79]. While the majority of these cases appear to resolve within the first year of treatment, persistent TBI symptoms have been found in 1–5 % of service members [78]. TBI can affect disability and long-term outcomes in many ways. First, it can impede a service member's ability to participate in rehabilitation. Second, studies have found that individuals with TBI are predisposed to chronic neurobehavioral and pain disorders that can greatly decrease a person's quality of life [75, 79].

Posttraumatic Stress Disorder

Posttraumatic stress disorder (PTSD) is the third most common disabling condition affecting service members who sustain battlefield injuries [5]. Yet, this condition does not just affect those who were recently deployed [78]. Veterans with PTSD are likely to have lower levels of life satisfaction and a more difficult time with personal and professional relationships than those without the condition [80]. Similar to TBI, patients who have PTSD are also at increased risk of developing pain-related disabilities, and PTSD can significantly complicate rehabilitation and recovery from concomitant musculoskeletal injuries [78, 81]. Lastly, one study found that limb salvage patients had a significantly higher rate of PTSD than amputees (32 % vs. 18 %, respectively) [75]. While the cause for this discrepancy is not known, it is important to note when counseling limb salvage patients and formulating their treatment plan.

General Return to Duty

It has been found that those injuries that are able to be treated at lower levels of care without escalation to higher levels of care have up to a 90% chance of returning to duty, whereas those patients who need to be escalated to higher levels of care have return-to-duty rates as low as 0–3% [82]. An injured service member's job description also matters greatly when determining their ability to return to duty. In an analysis of amputees it was found that being a member of the Special Forces significantly increased the likelihood of an amputee being found fit for duty than any other military occupational specialty [83]. In terms of returning to duty with a more elective procedure, 86% of active duty personnel who underwent total knee or hip arthroplasty returned to active duty, and 70% were able to deploy to the combat zone and complete their tour [84].

Research examining the factors that are related to successful return to duty following musculoskeletal injuries and conditions is lacking. Currently, return-to-duty criteria are based on expert opinion and clinical judgment rather than solid scientific evidence. This may be why recurrence rates following injury in athletes and military service members are so high. There is a critical need to identify the factors at the time of injury, and at the time of return to duty, that are associated with successful return to duty and reduce the risk of reinjury. These factors can be used to develop and implement evidence-based criteria for return to duty that contribute to secondary prevention efforts in high-risk military populations.

Summary

The cumulative effect of an all-volunteer military force and 14 years of continuous conflict have led to significantly elevated disability determinations and loss of the fighting strength and have had a considerable impact on force readiness. While recruiting and combat strength have maintained numbers, the burden of musculoskeletal injury and disability medical costs remain substantial.

References

1. Bell NS, et al. The changing profile of disability in the U.S. Army: 1981–2005. *Disabil Health J.* 2008;1(1):14–24.
2. Sharma L, et al. Knee adduction moment, serum hyaluronan level, and disease severity in medial tibiofemoral osteoarthritis. *Arthritis Rheum.* 1998;41(7):1233–40.
3. Masini BD, et al. Resource utilization and disability outcome assessment of combat casualties from Operation Iraqi Freedom and Operation Enduring Freedom. *J Orthop Trauma.* 2009;23(4):261–6.

4. Harrold LR, et al. Evaluating the predictive value of osteoarthritis diagnoses in an administrative database. *Arthritis Rheum.* 2000;43(8):1881–5.
5. Schouten JS, de Bie RA, Swaen G. An update on the relationship between occupational factors and osteoarthritis of the hip and knee. *Curr Opin Rheumatol.* 2002;14(2):89–92.
6. Provencher MR, et al. An analysis of shoulder outcomes scores in 275 consecutive patients-disease-specific correlation across multiple shoulder conditions. *Mil Med.* 2012;177:975–82.
7. Provencher MT, et al. A prospective analysis of 179 type 2 superior labrum anterior and posterior repairs: outcomes and factors associated with success and failure. *Am J Sports Med.* 2013;41(4):880–6.
8. Dumont GD, Golijanin P, Provencher MT. Shoulder instability in the military. *Clin Sports Med.* 2014;33(4):707–20.
9. Waterman BR, et al. Outcomes after Bankart repair in a military population: predictors for surgical revision and long-term disability. *Arthroscopy.* 2014;30(2):172–7.
10. Ozturk BY, et al. Return to sports after arthroscopic anterior stabilization in patients aged younger than 25 years. *Arthroscopy.* 2013;29(12):1922–31.
11. Gerometta A, et al. Arthroscopic Bankart shoulder stabilization in athletes: return to sports and functional outcomes. *Knee Surg Sports Traumatol Arthrosc.* 2014.
12. Dickens JF, et al. Return to play and recurrent instability after in-season anterior shoulder instability: a prospective multicenter study. *Am J Sports Med.* 2014;42:2842–50.
13. Harris JD, et al. Long-term outcomes after Bankart shoulder stabilization. *Arthroscopy.* 2013;29(5):920–33.
14. Bhatia S, et al. The outcomes and surgical techniques of the Latarjet procedure. *Arthroscopy.* 2014;30(2):227–35.
15. Mizuno N, et al. Long-term results of the Latarjet procedure for anterior instability of the shoulder. *J Shoulder Elbow Surg.* 2014;23(11):1691–9.
16. Bhatia S, et al. Early return to work in workers' compensation patients after arthroscopic full-thickness rotator cuff repair. *Arthroscopy.* 2010;26(8):1027–34.
17. Holtby R, Razmjou H. Impact of work-related compensation claims on surgical outcome of patients with rotator cuff related pathologies: a matched case-control study. *J Shoulder Elbow Surg.* 2010;19(3):452–60.
18. Mohtadi NG, et al. A randomized clinical trial comparing open to arthroscopic acromioplasty with mini-open rotator cuff repair for full-thickness rotator cuff tears: disease-specific quality of life outcome at an average 2-year follow-up. *Am J Sports Med.* 2008;36(6):1043–51.
19. Gill HS, O'Connor JJ. Heelstrike and the pathomechanics of osteoarthritis: a pilot gait study. *J Biomech.* 2003;36(11):1625–31.
20. Marchessault JA, McKay PL, Hammert WC. Management of upper limb amputations. *J Hand Surg Am.* 2011;36(10):1718–26.
21. Behrend C, et al. Update on advances in upper extremity prosthetics. *J Hand Surg Am.* 2011;36(10):1711–7.
22. Felson DT, et al. The incidence and natural history of knee osteoarthritis in the elderly. The Framingham osteoarthritis study. *Arthritis Rheum.* 1995;38(10):1500–5.
23. Tennent DJ, et al. Characterisation and outcomes of upper extremity amputations. *Injury.* 2014;45(6):965–9.
24. Gandevia SC, Refshauge KM, Collins DF. Proprioception: peripheral inputs and perceptual interactions. *Adv Exp Med Biol.* 2002;508:61–8.
25. Kumar AR, et al. Lessons from the modern battlefield: successful upper extremity injury reconstruction in the subacute period. *J Trauma.* 2009;67(4):752–7.
26. Bernstein ML, Chung KC. Early management of the mangled upper extremity. *Injury.* 2007;38(Suppl 5):3–7.
27. Kopec JA, et al. Descriptive epidemiology of osteoarthritis in British Columbia, Canada. *J Rheumatol.* 2007;34(2):386–93.
28. Blair JA PJ, Schoenfeld AJ, Cross Rivera JD, Grenier ES, Lehman RA, Hsu JR. Skeletal trauma research consortium (STReC), spinal column injuries among Americans in the global war on terrorism. *J Bone Jt Surg Am.* 2012;94:e135(1–9).

29. Blair JA, et al. Are spine injuries sustained in battle truly different? *Spine J.* 2012;12(9):824–9.
30. United States Bone and Joint Decade. Arthritis and related conditions. In the burden of musculoskeletal diseases in the United States. Rosemont: American Academy of Orthopaedic Surgeons; 2008. pp. 71–96.
31. Du Bois M, Szpalski M, Donceel P. Patients at risk for long-term sick leave because of low back pain. *Spine J.* 2009;9(5):350–9.
32. Friedman BW, et al. Predicting 7-day and 3-month functional outcomes after an ED visit for acute nontraumatic low back pain. *Am J Emerg Med.* 2012;30(9):1852–9.
33. Shaha JS, et al. Return to an athletic lifestyle after osteochondral allograft transplantation of the knee. *Am J Sports Med.* 2013;41(9):2083–9.
34. Krych AJ, et al. Return to athletic activity after osteochondral allograft transplantation in the knee. *Am J Sports Med.* 2012;40(5):1053–9.
35. Mithoefer K, et al. Return to sports participation after articular cartilage repair in the knee: scientific evidence. *Am J Sports Med.* 2009;37(Suppl 1):167–76.
36. Barber-Westin SD, Noyes FR. Factors used to determine return to unrestricted sports activities after anterior cruciate ligament reconstruction. *Arthroscopy.* 2011;27(12):1697–705.
37. Kamath GV MT, Creighton RA, Viradia N, Taft TN, Spang JT. Anterior cruciate ligament injury, return to play, and reinjury in the elite collegiate athlete: analysis of an NCAA division I cohort. *Am J Sports Med.* 2014;30(42):1638–43.
38. McCullough KA, Phelps KD, Spindler KP, Matava MJ, Parker RD, MOON Group, Reinke EK. Return to high school- and college-level football after anterior cruciate ligament reconstruction: a multicenter orthopaedic outcomes network (MOON) cohort study. *Am J Sports Med.* 2012;40(11):2523–9.
39. Friel NA, Chu CR. The role of ACL injury in the development of posttraumatic knee osteoarthritis. *Clin Sports Med.* 2013;32(1):1–12.
40. Rue JP, Pickett A. Meniscal repair and transplantation in the military active-duty population. *Clin Sports Med.* 2014;33(4):641–53.
41. Jones JC, et al. Incidence and risk factors associated with meniscal injuries among active-duty US military service members. *J Athl Train.* 2012;47(1):67–73.
42. Doukas WC, et al. the military extremity trauma amputation/limb salvage (metals) study: outcomes of amputation versus limb salvage following major lower-extremity trauma. *J Bone Joint Surg Am.* 2013;95(2):138–45.
43. Michaud CM, et al. The burden of disease and injury in the United States 1996. *Popul Health Metr.* 2006;4:11.
44. Keeling JJ, et al. Comparison of functional outcomes following bridge synostosis with non-bone-bridging transistibial combat-related amputations. *J Bone Joint Surg Am.* 2013;95(10):888–93.
45. Ebrahimzadeh MH, et al. Long-term clinical outcomes of war-related hip disarticulation and transpelvic amputation. *J Bone Joint Surg Am.* 2013;95(16):e114(1–6).
46. Kopec JA, et al. Trends in physician-diagnosed osteoarthritis incidence in an administrative database in British Columbia, Canada, 1996–1997 through 2003–2004. *Arthritis Rheum.* 2008;59(7):929–34.
47. Blair JA PJ, Blank RV, Owens JG, Hsu JR. Skeletal trauma research consortium (STReC), return to duty after integrated orthotic and rehabilitation initiative. *J Orthop Trauma.* 2014;28(4):e70–4.
48. Krueger CA, Wenke JC. Initial injury severity and social factors determine ability to deploy after combat-related amputation. *Injury.* 2014;45(8):1231–5.
49. Bedigrew KM, et al. Can an integrated orthotic and rehabilitation program decrease pain and improve function after lower extremity trauma? *Clin Orthop Relat Res.* 2014;472(10):3017–25.
50. MacKenzie EJ BM, Pollak AN, Webb LX, Swiontkowski MF, Kellam JF, Smith DG, Sanders RW, Jones AL, Starr AJ, McAndrew MP, Patterson BM, Burgess AR, Castillo RC. Long-term persistence of disability following severe lower-limb trauma. *J Bone Jt Surg Am.* 2005;87:1801–9.

51. Johnson AE, Cross JD. Impact of traumatic arthritis on a cohort of combat casualties. American Academy of Orthopaedic Surgeons annual meeting. 2011. San Diego, CA.
52. Krueger CA, Wenke JC, Ficke JR. Ten years at war: comprehensive analysis of amputation trends. *J Trauma Acute Care Surg.* 2012;73(6 Suppl 5):S438–44.
53. Hochberg MC. Epidemiology and genetics of osteoarthritis. *Curr Opin Rheumatol.* 1991;3(4):662–8.
54. Napierala MA, et al. Infection reduces return-to-duty rates for soldiers with type III open tibia fractures. *J Trauma Acute Care Surg.* 2014;77(3 Suppl 2):S194–7.
55. Lawrence RC, et al. Estimates of the prevalence of arthritis and other rheumatic conditions in the United States. Part II. *Arthritis Rheum.* 2008;58(1):26–35.
56. Richmond SA, et al. Are joint injury, sport activity, physical activity, obesity, or occupational activities predictors for osteoarthritis? A systematic review. *J Orthop Sports Phys Ther.* 2013;43(8):515–B19.
57. Oliveria SA, et al. Incidence of symptomatic hand, hip, and knee osteoarthritis among patients in a health maintenance organization. *Arthritis Rheum.* 1995;38(8):1134–41.
58. Lohmander LS, et al. The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. *Am J Sports Med.* 2007;35(10):1756–69.
59. Lohmander LS, et al. High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players twelve years after anterior cruciate ligament injury. *Arthritis Rheum.* 2004;50(10):3145–52.
60. Seidler A, et al. The role of cumulative physical work load in symptomatic knee osteoarthritis—a case-control study in Germany. *J Occup Med Toxicol.* 2008;3:14.
61. Felson DT. Obesity and vocational and avocational overload of the joint as risk factors for osteoarthritis. *J Rheumatol Suppl.* 2004;70:2–5.
62. Felson DT, et al. Osteoarthritis: new insights. Part 1: the disease and its risk factors. *Ann Intern Med.* 2000;133(8):635–46.
63. Felson DT, Zhang Y. An update on the epidemiology of knee and hip osteoarthritis with a view to prevention. *Arthritis Rheum.* 1998;41(8):1343–55.
64. Felson DT. Risk factors for osteoarthritis: understanding joint vulnerability. *Clin Orthop Relat Res.* 2004(Suppl 427):S16–21.
65. Issa SN, Sharma L. Epidemiology of osteoarthritis: an update. *Curr Rheumatol Rep.* 2006;8(1):7–15.
66. Englund M, Lohmander LS. Risk factors for symptomatic knee osteoarthritis fifteen to twenty-two years after meniscectomy. *Arthritis Rheum.* 2004;50(9):2811–9.
67. Patzkowski JC, et al. The changing face of disability in the US Army: the Operation Enduring Freedom and Operation Iraqi Freedom effect. *J Am Acad Orthop Surg.* 2012;20(Suppl 1):S23–30.
68. Cameron KL, Owens BD. The burden and management of sports-related musculoskeletal injuries and conditions within the US military. *Clin Sports Med.* 2014;33(4):573–89.
69. Cameron KL, Owens BD, DeBerardino TM. Incidence of ankle sprains among active-duty members of the United States Armed Services from 1998 through 2006. *J Athl Train.* 2010;45(1):29–38.
70. Owens BD, et al. Incidence of shoulder dislocation in the United States military: demographic considerations from a high-risk population. *J Bone Joint Surg Am.* 2009;91(4):791–6.
71. Owens BD, et al. Incidence of anterior cruciate ligament injury among active duty U.S. military servicemen and servicewomen. *Mil Med.* 2007;172(1):90–1.
72. Scher DL, et al. The incidence of primary hip osteoarthritis in active duty US military service members. *Arthritis Rheum.* 2009;61(4):468–75.
73. Cameron KL, et al. Incidence of physician diagnosed osteoarthritis among active duty United States military service members. *Arthritis Rheum.* 2011;63(10):2974–82.
74. Rivera JC, et al. Posttraumatic osteoarthritis caused by battlefield injuries: the primary source of disability in warriors. *J Am Acad Orthop Surg.* 2012;20(Suppl 1):S64–9.
75. Davis MA, et al. The association of knee injury and obesity with unilateral and bilateral osteoarthritis of the knee. *Am J Epidemiol.* 1989;130(2):278–88.

76. Scholten JD, et al. Analysis of US veterans health administration comprehensive evaluations for traumatic brain injury in Operation Enduring Freedom and Operation Iraqi Freedom veterans. *Brain Inj.* 2012;26(10):1177–84.
77. Potter MQ, et al. Psychological distress negatively affects self-assessment of shoulder function in patients with rotator cuff tears. *Clin Orthop Relat Res.* 2014;472:3926–32.
78. Otis JD, et al. Complicating factors associated with mild traumatic brain injury: impact on pain and posttraumatic stress disorder treatment. *J Clin Psychol Med Settings.* 2011;18(2):145–54.
79. Hootman JM, Helmick CG. Projections of US prevalence of arthritis and associated activity limitations. *Arthritis Rheum.* 2006;54(1):226–9.
80. Schnurr PP, et al. Posttraumatic stress disorder and quality of life: extension of findings to veterans of the wars in Iraq and Afghanistan. *Clin Psychol Rev.* 2009;29(8):727–35.
81. Outcalt SD, et al. Pain experience of Iraq and Afghanistan Veterans with comorbid chronic pain and posttraumatic stress. *J Rehabil Res Dev.* 2014;51(4):559–70.
82. Cohen SP, et al. Spine-area pain in military personnel: a review of epidemiology, etiology, diagnosis, and treatment. *Spine J.* 2012;12(9):833–42.
83. Belisle JG, Wenke JC, Krueger CA. Return-to-duty rates among US military combat-related amputees in the global war on terror: job description matters. *J Trauma Acute Care Surg.* 2013;75(2):279–86.
84. Glebus GP, et al. Return to duty and deployment after major joint arthroplasty. *J Arthroplasty.* 2013;28(8):1270–3.

Part II
**The Epidemiology of Musculoskeletal
Injuries by Anatomic Region**

Chapter 7

Shoulder Injuries

Christopher J. Tucker and Brett D. Owens

Introduction

In January 1994, the Armed Forces Epidemiological Board (AFEB) formed the Injury Prevention and Control Work Group to provide guidance and recommendations to the Army Surgeon General on the surveillance, prevention, and control of injuries in the military population [1]. The main objectives of the work group were to determine the magnitude of the injury problems across the military services, identify the causes, risk factors, and prevention strategies for injuries, assess the value of medical databases, and make recommendations with regard to research and prevention. The executive summary of this work group's report revealed several significant conclusions with regard to injuries in the military. They identified that injuries have a greater continual negative impact on the health and readiness of the US Armed Forces than any other category of medical complaint during both peacetime and combat. They also reported that training-related injuries treated on an outpatient basis contribute to a significant percentage of the overall morbidity in the military population, and subsequent disability results in significant compensation costs—exceeding \$750 million per year [1].

Sports injuries, motor vehicle crashes, and falls are the leading causes of injuries across all military services [2]. The military mantra that every soldier is an athlete holds true, in the sense that the military is a unique organization which requires every member to maintain physical fitness standards and evaluates each member with a biannual physical evaluation test. Physical training (PT) programs are crucial to maintaining the physical readiness of the Armed Forces, yet also result in high rates

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105

of musculoskeletal injury overall. Injury rates in recruits range from 10 to 15 per 100 per month for males, 15 to 25 per 100 per month for females, and 30 to 35 per month for Navy special warfare candidates [3, 4].

While training and occupational injuries contribute to significant disability, a substantial number of injuries also occur while military service members participate in recreational and competitive athletics. Over a 6-year surveillance period, Lauder et al. identified that the rates of sports injuries were 38 and 18 per 10,000 person-years for military men and women, respectively [5]. These injuries accounted for an average of 29,435 lost-duty days per year, with men losing an average 13 days per injury and women averaging 11 days per injury. While the knee was the most injured body part in both genders (more than 25% of all injuries), the shoulder was eighth in males and sixth in females (less than 5% of injuries in both genders) ([5], Fig. 7.1). Among joint dislocations, the shoulder was the most common in males with an overall injury rate of 0.44 per 10,000 person-years, occurring most commonly while participating in football, and second most common in females with an injury rate of 0.11 per 10,000 person-years, occurring most commonly in basketball [5].

Orthopedic injuries are the leading cause of disability for the Army, Navy, Air Force, and Marine Corps, resulting in between 22 and 63% of all Physical Evaluation Board (PEB) cases in various services [2, 6]. Overall, between 1 and 2% of all service members are evaluated annually for injury, with approximately 60% of these resulting in discharge or permanent retirement from service [2]. Musculoskeletal disorders are on the rise in the Army specifically, with initial data from 1992 showing that they accounted for 30% of all hospital admissions (28,000) and 40% of all soldier noneffective days (over 500,000 days). Based on US Naval Medical Evaluation Board data between 1989 and 1993, of the top 10 diagnoses of injury leading to disability, shoulder dislocation was eighth overall, and was the top diagnosis not involving the lower extremity, accounting for 2.9% of cases overall [6].

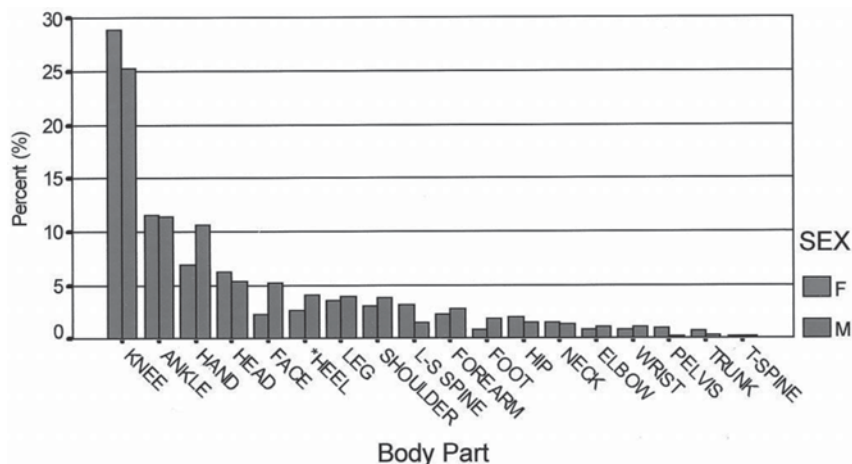


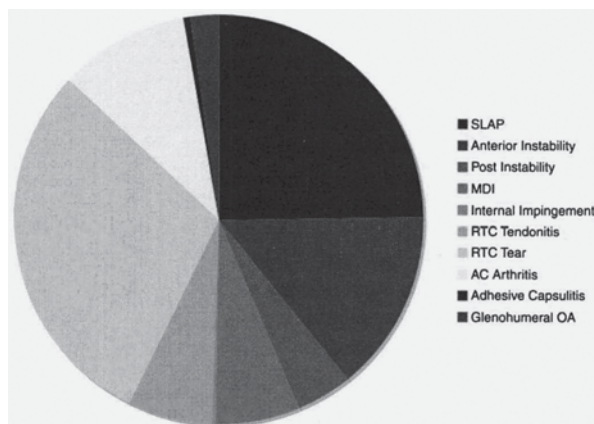
Fig. 7.1 Percent distribution of body areas injured in sports by gender [5]

Shoulder problems are common among US military service members and shoulder pain is a frequent complaint among service members who present to health-care professionals, both in the primary care and tertiary specialty clinic settings. Walsworth et al. conducted a prospective descriptive analysis of patients presenting to a tertiary military medical treatment facility to better characterize the diagnoses of those who presented with a chief complaint of shoulder pain [7]. Of those who eventually underwent surgery, 84% had more than one pathologic condition identified, with the three most common diagnoses including glenoid labrum injuries (80%), impingement with rotator cuff disease (49%), and instability (29%) [7]. Seventy-six percent of patients were able to recall a specific mechanism of injury, with the top 3 mechanisms of injury reported, in order of prevalence, including overuse related to physical training/sports, trauma related to physical training/sports, and fall [7].

This study highlights the complexity of shoulder conditions encountered in US military service members, which commonly involve multiple structures (84%), often have a prolonged duration of symptoms prior to presentation (average 33.75 months), and frequently have failed prolonged courses of nonoperative management prior to surgery (96%) [7]. The frequency with which military patients attribute their conditions to a specific injury (76%) is significantly higher than what has been described in civilian patients presenting to primary care settings, who have a reported mechanism of injury between 12 and 33% of the time [8]. The increased rate of known injury further suggests the inherent occupational risks associated with the military profession and its associated upper extremity physical demands and requirements.

Provencher et al. further examined the young, active military population who presented to orthopedic surgeons with a complaint of shoulder dysfunction [9]. Two hundred seventy-five consecutive patients, with a mean age of 36.5 years, completed a battery of validated outcomes questionnaires at their initial presentation to gain a better understanding of the spectrum and severity of pathology present among military patients with shoulder complaints. Ten classes of presenting diagnoses are represented in Fig. 7.2 [9]. The investigators found that military patients presenting

Fig. 7.2 Distribution of conditions in military patients presenting to orthopedic surgeons for shoulder pain [9]. *SLAP* superior labrum anterior posterior, *MDI* multidirectional instability, *RTC* rotator cuff, *AC* acromioclavicular, *OA* osteoarthritis



with shoulder complaints reported assessment scores approximately 50% of normal, across all conditions, representing fairly poor function overall [9]. Patients with superior labrum anterior posterior (SLAP) tears demonstrated the lowest overall scores, reflecting the highest degree of dysfunction, followed by instability and rotator cuff tears. Not surprisingly, those military members who required surgery had uniformly lower scores than those who were successfully treated nonoperatively.

Combat Shoulder Wounds

As discussed in Chap. 3, disease and non-battle injuries (DNBIs) continue to be a leading cause of morbidity and disability among troops deployed to Iraq and Afghanistan for Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF), respectively. Skeehan et al. conducted a recent epidemiological survey of deployed soldiers and found that 19.5% of all soldiers reported at least one DNBI and 85% sought care at least once during their deployment for symptoms [10]. The two most frequent causes of injury were sports/athletics and heavy gear lifting, with frequencies of 22.3 and 19.6%, respectively [10]. Belmont et al. reported on the DNBIs sustained by a US Army Brigade Combat Team during a counterinsurgency campaign in OIF. They found that musculoskeletal injuries were the most frequent body system casualties and accounted for 50.4% of all DNBIs [11]. Conditions related to the shoulder accounted for 11.8% of all DNBIs during the study period, the fifth most common body region behind the hand, knee, ankle, and lumbar spine. First-time shoulder dislocation was the fourth most common injury overall, behind ankle sprain, anterior cruciate ligament (ACL) rupture, and plantar fasciitis, with an incidence rate (IR) of 1.2 per 1000 soldier combat-years [11]. This compares similarly to previously reported IRs of 1.69 per 1000 person-years in the US Military as a whole and is approximately tenfold higher than the rates reported in civilian populations of between 0.11 and 0.24 per 1000 person-years [12, 13].

Roy recently examined another brigade combat team involved in operations in Afghanistan over a 15-month period in 2006–2007 to determine the prevalence of musculoskeletal diagnoses as well as mechanisms of injury in the deployed setting. This study better defined the at-risk nature of the military occupation in a deployed setting with regard to the shoulder. The shoulder was the fourth most frequently injured body region, affecting 164 of 1619 participants (10.1%) [14]. When broken down by Military Occupational Specialty (MOS), shoulder injuries were most prevalent in engineers, at 12% [14]. Engineers and maintenance personnel also had the highest percentage of shoulder impingement syndrome. This can be attributable to a number of factors, but likely represents the risk of overhead lifting combined with operating heavy equipment inherent within a military engineer's profession. Interestingly, this study confirmed that engineers sustain more upper extremity injuries in the deployed setting at a rate of 25% as compared to 15% in the non-deployed engineer unit [14].

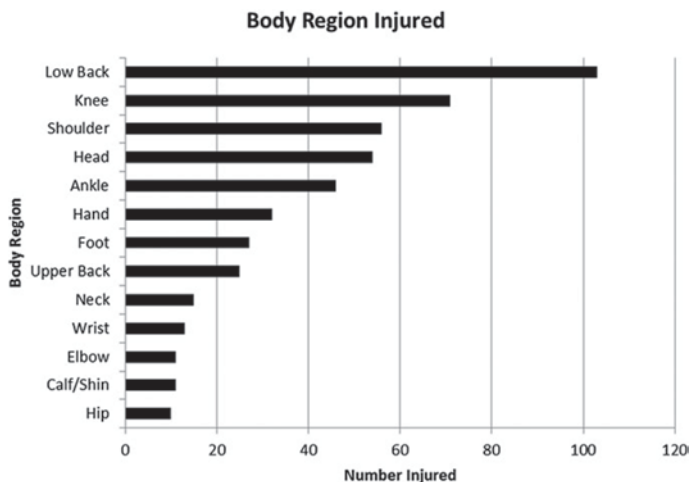


Fig. 7.3 Anatomical body regions injured most frequently during a 12-month deployment to Afghanistan [15]

Risk factors for injury in the deployed setting have been examined. In one cohort of troops in Afghanistan, the shoulder was the third most common body region injured with an incidence of 10%, with an overall average of 8.5 days of limited duty per injury (Fig. 7.3, [15]). The most frequent activities leading to injury included lifting and carrying (9.8%), dismounted patrolling (9.6%), and physical training (8.0%) [15]. Specific risk factors associated with higher incidence of injury included older age, higher enlisted rank, female gender, higher duration of deployment in months, longer strength training sessions, heaviest load worn, and heavier or more frequent lifting tasks [15].

Roy further examined the association between lifting tasks and injuries during the early portion (initial 3 months) of a Stryker Brigade Combat Team's deployment to Afghanistan between July 2009 and July 2010. Soldiers reported working on average 6 days per week and wearing their armored vest and carrying additional load (totaling a mean of 47.7 lbs) for >8 h/day [16]. Over 23% of soldiers sustained an injury in the third month of deployment, with the shoulder the second most common anatomical region affected at 14.5%. Gender, more days per week of lifting objects, and higher height of objects lifted were all significantly associated with injury [16].

Of the top 15 most frequently treated diagnoses encountered in the deployed setting, three involved the shoulder with impingement accounting for 3% of all diagnoses, acromioclavicular (AC) separation 1.6%, and pectoralis strain 0.7% [14]. Three of the top five most common mechanisms of injury were overuse (22%), weight lifting in the gym (8%), and sports (8%), which differ from the most common mechanisms of injury in the non-deployed setting of falls, vehicle accidents, and sports [1, 14]. With regard to shoulder-specific injuries, the incidence of shoulder injuries seen in Afghanistan (10.1%) is lower than that reported from Iraq (17.0%) [14, 17]. One postulated explanation for this discrepancy is related to the

wear of the Deltoid Axillary Protector (DAP) augmentation to the personal Interceptor Body Armor (IBA) while in Iraq, yet not in Afghanistan. The DAP consists of two separate ambidextrous components—the deltoid protector and the axillary protector, which are added to the protective vest system. Given the frequency of overuse injuries and shoulder impingement syndrome, the additional weight and possible altered shoulder biomechanics from the DAP may have contributed to a higher prevalence of shoulder injuries. This potential negative effect of the DAP in relation to overuse injuries must be weighed against the reported potential benefits in preventing direct shoulder injuries related to blast and penetrating trauma. Gondusky et al. reported on the injury rates in one Marine Light Armored Reconnaissance Battalion during OIF while the unit was field-testing the shoulder and axillary protector, and reported an overall shoulder injury rate from blast and penetrating trauma of 5% [18].

Owens et al. reviewed the Joint Theater Trauma Registry (JTTR) for all traumatic wounds sustained by US service members in OIF and OEF from October 2001 through January 2005, excluding DNBIIs [19]. They found a total of 1566 soldiers sustained 6609 combat wounds, and of these, 1281 soldiers had sustained 3575 extremity combat wounds, with 53% penetrating soft-tissue wounds and 26% fractures [19]. The 915 fractures were evenly distributed between the upper (461, 50%) and lower extremities (454, 50%), with 45 (9.8%) of the upper extremity fractures occurring in the clavicle (13) and scapula (32) [19]. Fifty-three percent of the clavicle fractures and 87% of the scapula fractures were open [19]. Overall, the shoulder accounted for 5% of all open fractures in OIF and OEF, which compares similarly to the only other conflict for which we have reported open shoulder fracture data—Operation Just Cause—with a 7% incidence [19, 20].

Mack et al. also reviewed open periarticular shoulder fractures, reviewing one tertiary care treatment facility's experience between March 2003 and January 2007 during OIF/OEF [21]. Reviewing 44 patients with open periarticular shoulder fractures, they found these to be extremely complicated injuries with high rates of associated neurologic (41%), vascular (23%), and other (86%) injuries [21]. Forty-three percent of patients had a shoulder girdle injury with multiple fractures, with the top bones involved including the proximal humerus (66%), acromion (36%), glenoid (25%), clavicle (23%), and coracoid (18%) [21]. Treatment challenges were highlighted by the high complication rates, with heterotopic ossification in 37% of patients, postoperative deep infection/osteomyelitis in 14%, nonfatal pulmonary embolus in 11%, wound dehiscence in 6%, and an overall amputation rate of 9% [21].

Orthopedic injuries account for a significant proportion of long-term disability and subsequent discharge from military service in veterans injured during OIF and OEF. Army Physical Evaluation Board records of the 464 service members wounded between October 2001 and January 2005 reveal that 69% of soldiers had unfitting orthopedic conditions [22]. Detailed descriptive analysis of combat-related orthopedic injuries by anatomic region in this population reveals that the shoulder alone accounts for 8% of injuries, 10% of disabling conditions, and an average percent disability for the service member of 23%. [22].

Shoulder Girdle Injuries

Acromioclavicular Joint Sprains

Acromioclavicular (AC) joint injury is common among young athletes, and given the correlation in physical demands between competitive athletes and active-duty military personnel, it is also prevalent in the military population [23, 24]. AC joint injuries commonly occur in the third decade of life and have been reported to occur five times as often in males as compared to females in the civilian population [25]. However, data collected in a prospective, longitudinal cohort of US Military Academy cadets over a recent 4-year period show less of a discrepancy between the incidence in male and female cadets, with male patients only twice as likely to sustain an AC joint injury as females [24]. This is likely attributable to the younger mean age within this cohort, as well as the higher frequency of participation of females in higher risk intercollegiate athletic competition.

Pallis et al. reported an overall IR of 9.2 AC joint injuries per 1000 person-years in US Military Academy cadets [24]. The majority of these injuries (89%) were classified as low-grade—type I or II according to the Rockwood classification system—with the vast majority of injuries (91%) occurring as a result of participation in athletics [24, 25]. The distribution of injuries included AC sprains (87%), fractures (7%), sternoclavicular joint sprains (3%), and inflammation/osteolysis (3%). AC joint injuries resulted in an average of 18.4 days of duty lost per athlete, with low-grade injuries averaging 10.4 days versus high-grade injuries at 63.7 days per injury [24]. The IR of injury was significantly higher in intercollegiate athletes than intramural athletes, with an incidence rate ratio (IRR) of 2.11 [24]. The rate of surgical intervention was 19 times higher in high-grade injuries than low-grade injuries [24].

Clavicle Fractures

Clavicle fractures are one of the common injuries of the shoulder girdle both in the civilian and military populations, accounting for up to 5% of all adult fractures and 35% of shoulder girdle injuries in the general population [26, 27]. They hold a particular importance with respect to potential disability in military service members given their unique occupational demands. Military service members not only frequently perform high-risk overhead lifting and pulling activities but also participate in daily physical fitness training programs including push-ups and pull-ups, mandatory combatives training, obstacle courses, and frequently wear heavy shoulder-borne equipment such as rucksacks and individual body armor for extended periods of time [16, 24]. Injury to the shoulder girdle, including clavicle fractures, can render a soldier entirely incapable of performing these occupation-specific tasks for a period of time.

The trend in civilian trauma practice has moved toward operative management of displaced midshaft clavicle fractures to attempt to improve on the higher nonunion rates and poorer patient-centered outcomes scores associated with nonoperative management in these patients [26, 28, 29]. This trend is particularly applicable to the military population as well, given the specific occupational disability associated with painful midshaft clavicle fracture nonunions after nonoperative management in soldiers [30]. Huh et al. have challenged the notion that military patients cannot tolerate a plate on the clavicle due to the potential for symptomatic hardware, and shown promising early outcomes with plate fixation of midshaft clavicle fractures in a military cohort, with 93% union rate at 3 months, 75% patient satisfaction rate, and 79% return of full shoulder motion [26]. They also reported on military-specific outcomes with 75% able to do push-ups, 71% able to wear body armor, 68% able to wear a rucksack, and even in the short (6 month) study window, 21% deployed after surgery [26].

Despite these promising results, others have challenged the notion of plate fixation in military patients. Wenninger et al. looked retrospectively at 62 patients undergoing surgical management of midshaft clavicle fractures and demonstrated a statistically higher complication rate in the plate fixation group (31%) compared with the Hagie pin fixation group (9%) [31]. The most common complication in both groups was symptomatic hardware and soft-tissue irritation, at an overall rate of 16% [32].

Hsiao et al. queried the Defense Medical Epidemiology Database between 1999 and 2008 to determine the incidence of clavicle fractures in the US military and to identify any potential demographic risk factors for injury [33]. The authors reported a total of 12,514 clavicle fractures in an at-risk population with 13,770,767 person-years of follow-up, for an overall IR of 0.91 per 1000 person-years in the US Military [33]. Specific demographic variables that were significantly associated with increased incidence of clavicle fracture included sex, age, race, branch of service, and rank [33]. Men sustained clavicle fractures more than twice as often as females, with an IR of 0.67 per 1000 person-years in males compared to 0.29 for females. The adjusted IRR for men compared to women is 2.30 [33]. Clavicle fractures occurred significantly more often in white service members than both black service members and those listing “other” as their race. The adjusted IR for white service members is 0.66 per 1000 person-years, 0.49 for service members in the “other” category, and 0.27 for black service members. This leads to a greater than twofold increased risk for white service members as compared to black service members, with an adjusted IRR of 2.45 [33]. Rates of clavicle fractures generally decline with increasing age, with the peak incidence of injury occurring in the age groups of <20 years and 20–24 years. Service members in the age groups <20, 20–24, and 25–29 years had calculated IRs that were 38, 42, and 18% higher, respectively, as compared to the >40-year-old group [33]. With respect to branch of service, the highest IR was found in those serving in the Marine Corps, followed by those in the Army, Air Force, and Navy. With respect to the Navy—the lowest risk category—the Marine Corps, Army, and Air Force had IRs that were 44, 16, and 6% higher [33]. Military rank was also associated with the incidence of clavicle

fracture, with the highest IR seen in the junior enlisted service members, followed in descending order by senior enlisted, junior officers, and senior officers. The IRs for junior enlisted, senior enlisted, and junior officers were 46, 35 and 12% higher when compared to senior officers [33]. Overall, the IR of clavicle fractures is higher in the US military population (0.91 per 1000 person-years) than rates seen previously published for urban, civilian population which have ranged between 0.06 and 0.50 per 1000 person-years [27, 33, 34]. Demographic factors at highest risk in the military population are male gender, white race, and age less than 30 years [33].

Glenohumeral Joint Instability

Instability

Glenohumeral joint instability is a common orthopedic problem that can lead to pain and decreased ability to participate in physically demanding activities such as competitive athletics and military-specific occupational requirements [35]. Studies have evaluated a cohort of young, physically active military cadets at the US military Academy as well as the military population as a whole to determine the true incidence and characteristics of shoulder instability in the military population [13, 36]. Their findings highlight the importance of addressing this condition in the military, both from an initial management and treatment standpoint and a preventative standpoint by addressing modifiable and non-modifiable risk factors.

Several studies have reported on the incidence of shoulder dislocation in civilian populations. Simonet et al. estimated the incidence of primary, anterior shoulder dislocation to be 0.08 per 1000 person-years for the general population of Olmstead County, Minnesota [37]. European studies have estimated incidences of 0.17 per 1000 person-years in an urban population in Denmark, and 0.24 per 1000 person-years in a town in Sweden [21, 38].

In the largest US civilian population-based study of shoulder dislocations presenting to emergency departments, Zacchilli et al. reported an incidence of 0.24 per 1000 person-years [39]. In this study, utilizing the National Electronic Injury Surveillance System, the male IR was calculated as 0.35 per 1000 person-years, an IRR of 2.64 relative to females, with 71.8% of all dislocations occurring in males [39]. When age was broken down by decade, the highest IR (0.48) occurred in those aged 20–29 years, with 46.8% of all dislocations occurring in patients aged 15–29 years. There were no differences identified based on race in this cohort [39].

Owens et al. demonstrated in a closed population study among US military Academy cadets that the incidence of first-time traumatic shoulder dislocation is an order of magnitude greater in these military academy cadets than in previously reported studies [36]. The probability of a shoulder instability event (defined as a subluxation or dislocation) is 2.8% per academic year, with an incidence proportion of 2.9% for males and 2.5% for females [36]. Overall, an IR of 4.35 per 1000

person-years was reported in this cohort [36]. The significantly higher IR in this study can be attributed both to the efficient methodology of data collection in a closed population as well as the younger age and higher activity level of these military cadets.

Of all instability events, 84.6% were subluxations and 15.4% were true glenohumeral dislocations, so when looking only at dislocation events, the incidence proportion is 0.43% overall [36]. The majority of overall instability events were in the anterior direction (88%), with 17 of 18 (94%) of the dislocations occurring in the anterior direction [36]. This is consistent with previous reports of anterior dislocation rates of 97% in the general population [38]. Mechanism of injury was recorded as well, showing that 43.6% of instability events were a result of contact injuries and 41% were from noncontact injuries [36]. High rates of intra-articular pathology were confirmed for both dislocations and subluxations. The high percentage of anterior dislocations with Bankart lesions (93%) and Hill–Sachs lesions (86%) in this military population is consistent with previous reports of Bankart tears and Hill–Sachs lesions in those who underwent surgery for instability, with rates of 97 and 90%, respectively [36, 40]. Rates of pathologic lesions in the subluxation subset were reported for the first time, with incidences of Bankart lesions in 49% and Hill–Sachs lesions in 48% [36].

When evaluating the entire military population for shoulder dislocation, using the Defense Medical Epidemiology Database, the overall IR was calculated to be 1.69 dislocations per 1000 person-years [36]. Again, this is tenfold higher than rates of 0.08–0.24 per 1000 person-years previously reported in civilian population studies [12, 37, 38]. Significant independent risk factors for injury included male sex, white race, and age less than 30 years [13]. The calculated IR for males was 1.82 compared to 0.90 for females; and when controlling for race, age, branch of service, and rank, the adjusted IRR for males compared to females was reported as 1.95 [13]. Those service members with white race had an injury rate of 1.78 compared to 1.59 for “other” races and 1.41 for black race. The adjusted rate ratio for white race was 1.25 compared to black race [13]. Age also had a significant impact on injury rates, with increasing rates associated with the youngest age categories. The highest IR (2.35) occurred in the youngest age group (younger than 20 years old), yet all of the categories less than 30 years old had significantly greater risk than the older age groups [13]. With respect to branch of service, the highest IRs were seen in the Army (2.34) and marines (2.28) [13]. Finally, military rank played a significant role in risk for shoulder dislocation, with both junior and senior enlisted ranks having significantly higher rates than commissioned officers. Unadjusted IRs for junior enlisted, senior enlisted, and officers were 2.20, 1.32, and 1.12 per 1000 person-years, respectively [13].

Superior Labrum Anterior Posterior Tears

Superior labrum anterior posterior (SLAP) tears are a source of shoulder pain and disability in young, active patients. Mechanisms of injury include direct trauma,

overhead traction to an outstretched arm, and repetitive overhead throwing motions especially in athletes. Military patients are at particular risk for injury given the physical nature of their profession, the risk of trauma, and demands of routine physical training. The incidence of SLAP lesions in military patients undergoing shoulder arthroscopy for pain, instability, or other reasons is significantly higher (38.6%) than in the civilian population (11.1%) [41]. Patients with a history of trauma (85.2%) or symptoms of instability were more likely to have a SLAP lesion [41]. Of the SLAP lesions identified in this cohort, 20.5% were type I, 69.3% were type II, 5.1% were type III, and 5.15% were type IV according to the Snyder classification [41, 42].

Waterman et al. recently conducted the first population-based study to evaluate the trends in the incidence of SLAP lesions in a young, physically active military population at risk for shoulder pathology between 2002 and 2009 [32]. The authors report that the most important finding of their research is that within the military population, male gender, increasing age, white race, enlisted rank, and service in the Marine Corps are associated with the highest incidence of SLAP lesions [32]. Overall, approximately two incident cases of SLAP tears were found for every 1000 person-years at risk during the study period [32].

There is a high incidence (90%) of associated shoulder pathology among patients who have arthroscopically diagnosed SLAP lesions [41]. Concomitant pathology was most frequently found in patients with type II SLAP lesions. In decreasing order of frequency, these findings included rotator cuff pathology (83%), Hill–Sachs lesions (69%), Bankart tears (63%), and anterior instability on examination under anesthesia (67%) [41].

Surgical management of SLAP tears in military patients, both in isolation and with associated pathology, has been shown to be successful [43, 44]. Arthroscopic repair of type II SLAP tears has been shown to have 94–97% good to excellent results at 1–3-year follow-up in civilian populations including overhead athletes, with 91% of patients regaining their pre-injury level of function [45–47]. Military service members have physical demands that have been shown to be unique from civilian occupations, and thus place significant demands on their shoulders—a particular challenge for surgeons caring for this demographic. Enad et al. have shown that arthroscopic treatment of SLAP lesions in military patients can yield results similar to previously published data on civilian populations despite these challenges [44]. In a cohort of 27 patients who underwent suture anchor repair of type II SLAP tears, at a mean follow-up of 30.5 months, 96% had returned to full duty at a mean of 4.4 months postoperative, and 97% eventually regained at least 80% of their previous level of function based on University of California, Los Angeles (UCLA) and American Shoulder and Elbow Surgeons (ASES) scores, with 76% returning to their previous level of recreational athletics outside of their military occupational specialty [44]. In a separate cohort of 36 age-matched active-duty males with isolated versus combined type II SLAP tears treated arthroscopically, Enad et al. demonstrated an identical return to duty rate of 94% in each group [43]. This study also highlighted the importance of treating concomitant pathology at the same time, with significantly better improvements in postoperative ASES scores and Visual Analog

Scale (VAS) pain scores in those who had surgical correction of concomitant extra-articular shoulder pathology at the same time as SLAP repair [43].

Pectoralis Major Tears

Rupture of the pectoralis major muscle or tendon is a rare injury, with an observed increase in frequency in recent decades likely attributable in part to the increased rates of recreational athletic participation in society [48]. Pectoralis tendon ruptures typically occur in activities requiring forcible shoulder flexion, such as weight training—specifically bench press—or activities with potential for forced, traumatic shoulder extension such as football, wrestling, or rugby [49, 50]. Military-specific unique mechanisms of injury have also been described, including a soldier rupturing the pectoralis major tendon in his “brake hand” while rappelling in an air-assault descent and another occurring to a paratrooper whose arm was caught in the risers of his parachute during a static-line deployment [51, 52]. White et al. demonstrated that 92 % of all major tendon ruptures in an active-duty military population, including pectoralis tendon injuries, occurred during participation in sports or similar physical activity requiring plyometric movements [48]. Peak incidence for pectoralis major tendon injury occurs in active males, aged 20–40 years old, which corresponds to a large proportion of the active-duty military population [53].

White et al. showed that pectoralis major tendon ruptures account for 14 % of all major tendon ruptures in an active-duty military population, and most commonly occur secondary to bench pressing (71 %) [48]. Descriptive statistics show that, by race, pectoralis major tendon injuries occur 71 % in blacks and 14 % each in whites and other races. When evaluating all major tendon ruptures, including pectoralis major, Achilles, patellar, and quadriceps, the rate ratio, when adjusted for age and gender, was 13.3 between blacks and whites, and 2.9 between Latinos and whites [48]. Age also played a significant role in risk for tendon injury, with only 8 % of injuries in subjects younger than 24 years, 55 % in those aged 25–34 years, and 37 % in those 35 years or older [48].

Both acute and chronic pectoralis major tendon ruptures have been treated successfully with surgical repair. In a retrospective review of 14 active-duty military patients over an 8-year period, Antosh et al. showed acceptable overall results with operative repair, and a statistically significant difference in better outcomes for the immediate repair group compared to the delayed group [53]. The mean age of the patients was 31.4 years (range 21–48) which is consistent with previous reports, and for 11 of 14 patients (79 %) the mechanism of injury was bench-pressing weights [53]. Unfortunately, some residual disability was common in this cohort, with a mean postoperative Disabilities of the Arm, Shoulder and Hand (DASH) score of 12.74, a mean 39 % reduction in maximal bench-press weight, and a mean 34 % reduction in 2-min push-up maximum reps based on patient-reported data [53].

Degenerative Conditions

Impingement and Rotator Cuff Disease

Subacromial impingement syndrome (SIS) is one of the most common causes for shoulder pain in the general population. This syndrome spans a range of pathology from subacromial bursitis to rotator cuff tendinopathy and both partial- and full-thickness rotator cuff tears [54]. The etiology of rotator cuff disease remains a subject of ongoing debate, yet is likely multifactorial with contributions from external impingement (from the acromion, coracoacromial ligament, and AC joint), intrinsic age-related tendon degeneration, repetitive trauma, and vascular compromise [54]. Nonsurgical management is the mainstay of initial treatment for patients with SIS, and surgical intervention has been shown to be successful for a majority of patients in whom this initial treatment fails. Options for surgical intervention include open or arthroscopic acromioplasty, debridement, bursectomy, and rotator cuff repair.

The incidence of rotator cuff disease in the general population has been reported, and it increases with age. Full-thickness rotator cuff tears are present in approximately 25% of people in their 60s and approximately 50% of people in their 80s [55]. Asymptomatic full-thickness rotator cuff tears are common, increasing in frequency with age, and are present approximately 50% of the time in patients over age 65 who have a contralateral symptomatic full-thickness rotator cuff tear [55].

Several studies have estimated the prevalence of both partial- and full-thickness rotator cuff tears in both cadaver specimens and using various imaging techniques in both asymptomatic and symptomatic patients. Cadaver and autopsy dissection studies estimate a prevalence of rotator cuff defects ranging from 5 to 40% in the general population [56, 57]. Lehman et al. found a relationship between full-thickness tears and age in a cadaver study with a prevalence of 6% in specimens less than 60 years old and 30% in those older than 60 years [58]. The location of partial-thickness tears has also been investigated, with reported incidences for bursal-sided (2.4%), intratendinous (7.2%), and articular-sided (3.6%) tears [59].

Imaging modalities such as ultrasound and magnetic resonance imaging (MRI) have been utilized to evaluate both asymptomatic and symptomatic patients for partial and complete rotator cuff tears. Rotator cuff tears have been shown to be present in asymptomatic individuals at an overall prevalence of between 17 and 34% and in symptomatic patients 36% of the time [60, 61].

In all studies, a higher prevalence of rotator cuff tears correlated to increased age. In asymptomatic subjects, Sher et al. demonstrated that MRI confirmed partial- and full-thickness tears in patients less than 40 years of age in 4 and 0%, respectively, in patients between 40 and 60 years of age in 24 and 4%, and in those older than 60 years in 26 and 28%, respectively [60]. Yamamoto et al. reported that overall 25.6% of individuals in their 60s have a rotator cuff tear and up to 50% of subjects in their 80s have a tear [61].

A recent systematic review revealed that traumatic rotator cuff tears are more likely to occur in a younger age bracket (mean age 54.7 years) than attritional,

chronic, atraumatic rotator cuff tears [62, 63]. This review examined specific tendon involvement with supraspinatus in 84 %, subscapularis in 78 %, and infraspinatus in 39 % [62]. Tear size was reported as <3 cm in 22 % of tears, 3–5 cm in 36 %, and >5 cm in 42 % [62]. Thus, when compared to atraumatic, attritional tears, the cohort of patients with traumatic tears were younger and had larger tears with significantly more subscapularis involvement [62].

Rotator cuff disease including impingement and partial- and full-thickness tears are among the most common of shoulder problems that affect US military service members. Walsworth et al. conducted a prospective descriptive analysis of patients presenting to a tertiary military medical treatment facility to characterize the diagnoses of those who presented with a chief complaint of shoulder pain. Of the 55 subjects, mean age of 40.6 years, who eventually underwent surgery, 84 % had more than one pathologic condition identified and impingement with rotator cuff disease (49 %) was the second most common pathologic condition encountered [7]. Seventy-six percent of patients were able to recall a specific mechanism of injury (top 3 including overuse related to physical training/sports, trauma related to physical training/sports, and fall), which further supports the higher incidence of traumatic rotator cuff tears in younger patient populations [7]. The most frequent concomitant injuries associated with impingement and rotator cuff tears in this military cohort included labral tears, instability, and AC joint arthritis [7].

Provencher et al. examined a cohort of 275 young, active military patients with a mean age of 36.5 years who presented to orthopedic surgeons with a complaint of shoulder dysfunction. Of the 10 categories of pathologic conditions, rotator cuff tear (both partial- and full-thickness) represented 29 % of all cases, and rotator cuff tendinopathy accounted for another 7 % (Fig. 7.2, [9]). This study also reported the considerable level of disability associated with these conditions and found that patients with partial- or full-thickness rotator cuff tears presented with mean Western Ontario Rotator Cuff Index (WORC) scores that were considerably worse than those with impingement alone [9].

Glenohumeral Joint Osteoarthritis

Osteoarthritis is the most common cause of disability in adults in the USA, affecting almost 27 million people in the general population [64]. Osteoarthritis is also the most common cause of disability in US military service members who are medically separated from active service [22].

Cross et al. reviewed the records of 464 military service members wounded in combat between October 2001 and January 2005 who underwent Army Physical Evaluation Board hearings to determine fitness for continued military service. Orthopedic conditions made up 69 % of all unfitting conditions, and degenerative arthritis was the top-ranking condition overall for which military service members were found unfit for duty [22]. Degenerative arthritis secondary to combat injury accounted for 29 % of all unfitting conditions, with an average percent disability rating of 15 % [22].

Of those military service members with osteoarthritis as their primary unfitting condition, injuries to the shoulder were second only to spine in prevalence, occurring in 32% of patients in one cohort [65]. Combat injuries to the shoulder were determined to result in arthritis in 60% of cases, highlighting the severity of these downrange shoulder injuries and their lasting impact on the injured soldier via long-term disability [65]. Traumatic injury causes 94.4% of all cases of joint osteoarthritis in active-duty service members, with 75% of these conditions resulting from fractures or arthrotomies caused by explosive devices [65].

Treatment for end-stage posttraumatic osteoarthritis (PTOA) involves total joint arthroplasty, most commonly in the hip, knee, and shoulder. The challenge in caring for these wounded warriors is that the average age of veterans with PTOA who undergo joint arthroplasty is much lower than that in the general population [66]. Fehringer et al. examined data from the Veterans Administration (VA) National Surgical Quality Improvement Program (NSQIP) between the fiscal years 1999 and 2006 to review total joint arthroplasties in US military veterans [67]. They found that total shoulder arthroplasties (TSA) accounted for 2.3% of all joint arthroplasties in military veterans [67]. Interestingly, despite the longer mean operative time for TSA (3.0 h) as compared to total knee arthroplasty (TKA) (2.2 h) or total hip arthroplasty (THA) (2.4 h), both the 30-day mortality rates and postoperative complication rates for TSA were significantly lower. The 30-day mortality rates for THA, TKA, and TSA were 1.2, 1.1, and 0.4%, respectively. The overall postoperative complication rates for THA, TKA, and TSA were 7.6, 6.8, and 2.8%, respectively [67]. Controlling for multiple risk factors, it was determined that TSA resulted in shorter inpatient hospital stays, fewer postoperative complications, and fewer readmissions than both TKA and THA in the Veterans Health Administration (VA) population [67].

Conclusions

Shoulder injuries are common in US military service members. Occupational demands including mandatory physical training requirements and varied risks associated with combat training and deployment present a unique challenge to health-care providers caring for these individuals. Shoulder injuries contribute to significant lost-duty days in active-duty soldiers as well as long-term disability in those who retire or otherwise leave military service. Military service members experience a range of acute and chronic overuse injuries in the shoulder girdle region and these injuries have been associated with high rates of degenerative disease and osteoarthritis. The incidence of many shoulder injuries is significantly higher in the military population compared to civilians, which emphasizes the continuing need for effective delivery of orthopedic care to active-duty soldiers and veterans. Understanding the modifiable and non-modifiable risk factors for these shoulder injuries is also critical in developing and implementing primary prevention strategies to reduce the burden of shoulder injuries in military populations.

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References

1. Jones BH, Canham-Chervak M, Canada S, et al. Medical surveillance of injuries in the U.S. Military descriptive epidemiology and recommendations for improvement. *Am J Prev Med.* 2010;38 Suppl 1:S42–S60.
2. Jones BH, Hansen BC. An Armed Forces Epidemiological Board evaluation of injuries in the military. *Am J Prev Med.* 2000;18 Suppl 3:S14–S25.
3. Kaufman KR, Brodine S, Shaffer R. Military training-related injuries: surveillance, research, and prevention. *Am J Prev Med.* 2000;18 Suppl 3:54–63.
4. Peterson SN, Call MH, Wood DE, et al. Injuries in naval special warfare sea, air, and land personnel: epidemiology and surgical management. *Oper Tech Sports Med.* 2005;13:131–5.
5. Lauder TD, Baker SP, Smith GS, et al. Sports and physical training injury hospitalizations in the Army. *Am J Prev Med.* 2000;18 Suppl 3:118–28.
6. Songer TJ, LaPorte RE. Disabilities due to injury in the military. *Am J Prev Med.* 2000;18 Suppl 3:33–40.
7. Walsworth MK, Doukas WC, Murphy KP, et al. Descriptive analysis of patients undergoing shoulder surgery at a tertiary care military medical center. *Mil Med.* 2009;174:642–4.
8. Wofford JL, Mansfield RJ, Watkins RS. Patient characteristics and clinical management of patients with shoulder pain in U.S. primary care settings: secondary data analysis of the National Ambulatory Medical Care Survey. *BMC Musculoskelet Disord.* 2005;6:4.
9. Provencher MT, Frank RM, Macian D, et al. An analysis of shoulder outcomes scores in 275 consecutive patients: disease-specific correlation across multiple shoulder conditions. *Mil Med.* 2012;177:975–82.
10. Skeehan CD, Tribble DR, Sanders JW, et al. Nonbattle injury among deployed troops: an epidemiologic study. *Mil Med.* 2009;174:1256–62.
11. Belmont PJ Jr, Goodman GP, Waterman B, et al. Disease and nonbattle injuries sustained by a U.S. Army Brigade Combat Team during Operation Iraqi Freedom. *Mil Med.* 2010;175:469–76.
12. Nordqvst A, Petersson CJ. Incidence and causes of shoulder girdle injuries in an urban population. *J Shoulder Elbow Surg.* 1995;4:107–12.
13. Owens BD, Dawson L, Burks R, et al. Incidence of shoulder dislocation in the United States military: demographic considerations from a high-risk population. *J Bone Joint Surg Am.* 2009;91:791–6.
14. Roy TC. Diagnoses and mechanisms of musculoskeletal injuries in an infantry brigade combat team deployed to Afghanistan evaluated by the brigade physical therapist. *Mil Med.* 2011;176:903–8.
15. Roy TC, Knapik JJ, Ritland BM, et al. Risk factors for musculoskeletal injuries for soldiers deployed to Afghanistan. *Aviat Space Environ Med.* 2012;83:1060–6.
16. Roy TC, Ritland BM, Knapik JJ, et al. Lifting tasks are associated with injuries during the early portion of a deployment to Afghanistan. *Mil Med.* 2012;177:716–22.
17. Rhon DI. A physical therapist experience, observation, and practice with an infantry brigade combat team in support of Operation Iraqi Freedom. *Mil Med.* 2010;175:442–7.
18. Gondusky JS, Reiter MP. Protecting military convoys in Iraq: an examination of battle injuries sustained by a mechanized battalion during Operation Iraqi Freedom II. *Mil Med.* 2005;170:546–9.

19. Owens BD, Kragh JF, Macaitis J, et al. Characterization of extremity wounds in Operation Iraqi Freedom and Operation Enduring Freedom. *J Orthop Trauma*. 2007;21:254–7.
20. Jacob E, Erpelding JM, Murphy KP. A retrospective analysis of open fractures sustained by U.S. military personnel during Operation Just Cause. *Mil Med*. 1992;157:552–6.
21. Mack AW, Groth AT, Frisch HM, et al. Treatment of open periarticular shoulder fractures sustained in combat-related injuries. *Am J Orthop*. 2008;37:130–5.
22. Cross JD, Ficke JR, Hsu JR, et al. Battlefield orthopaedic injuries cause the majority of long-term disabilities. *J Am Acad Orthop Surg*. 2011;19Suppl 1:S1–S7.
23. Mazzocca AD, Arciero RA, Bicos J. Evaluation and treatment of acromioclavicular joint injuries. *Am J Sports Med*. 2007;35:316–29.
24. Pallis M, Cameron KL, Svoboda SJ, et al. Epidemiology of acromioclavicular joint injury in young athletes. *Am J Sports Med*. 2012;40:2072–7.
25. Rockwood CJ, Williams G, Young D. Disorders of the acromioclavicular joint. In: Rockwood CJ, Matsen FA III, Editors. *The shoulder*. 2nd ed. Philadelphia: WB Saunders; 1998. pp. 483–553.
26. Huh J, Posner MA, Bear RR, et al. Performance of military tasks after clavicle plating. *Mil Med*. 2011;176:950–5.
27. Nordqvst A, Petersson C. The incidence of fractures of the clavicle. *Clin Orthop Relat Res*. 1994;300:127–32.
28. Canadian Orthopaedic Trauma Society. Nonoperative treatment compared with plate fixation of displaced midshaft clavicular fractures. A multicenter, randomized clinical trial. *J Bone Joint Surg Am*. 2007;89:1–10.
29. McKee MD, Pederson EM, Jones C, et al. Deficits following nonoperative treatment of displaced midshaft clavicular fractures. *J Bone Joint Surg Am*. 2006;88:35–40.
30. Edwards A, Khan F, Smith AL. Five case studies of soldiers with painful clavicular fracture non-union. *J R Army Med Corps*. 1999;145:31–3.
31. Wenninger JJ Jr, Dannenbaum JH, Branstetter JG, et al. Comparison of complication rates of intramedullary pin fixation versus plating of midshaft clavicle fractures in an active duty military population. *J Surg Orthop Adv*. 2013;22:77–81.
32. Waterman BR, Cameron KL, Hsiao M, et al. Trends in the diagnosis of SLAP lesions in the US military. *Knee Surg Sports Traumatol Arthrosc*. 2013; Epub ahead of print, doi: 10.1007/s00167-013-2798-z.
33. Hsiao MS, Cameron KL, Huh J, et al. Clavicle fractures in the United States military: incidence and characteristics. *Mil Med*. 2012;177:970–4.
34. Nowak J, Mallmin H, Larsson S. The aetiology and epidemiology of clavicular fractures. A prospective study during a two-year period in Uppsala, Sweden. *Injury*. 2000;31:353–8.
35. DeBerardino TM, Arciero RA, Taylor DC, et al. Prospective evaluation of arthroscopic stabilization of acute, initial anterior shoulder dislocations in young athletes. Two- to five-year follow-up. *Am J Sports Med*. 2001;29:586–92.
36. Owens BD, Duffey ML, Nelson BJ, et al. The incidence and characteristics of shoulder instability at the United States Military Academy. *Am J Sports Med*. 2007;35:1168–73.
37. Simonet WT, Melton LJ, Cofield RH, et al. Incidence of anterior shoulder dislocation in Olmstead County, Minnesota. *Clin Orthop Relat Res*. 1984;186:186–91.
38. Kroner K, Lind T, Jensen J. The epidemiology of shoulder dislocations. *Arch Orthop Trauma Surg*. 1989;108:288–90.
39. Zacchilli MA, Owens BD. Epidemiology of shoulder dislocations presenting to emergency departments in the United States. *J Bone Joint Surg Am*. 2010;92:542–9.
40. Taylor DC, Arciero RA. Pathologic anatomy associated with dislocation of the shoulder: arthroscopic and physical examination findings in first-time, traumatic anterior dislocations. *Am J Sports Med*. 1997;25:306–11.
41. Kampa RJ, Clasper J. Incidence of SLAP lesions in a military population. *J R Army Med Corps*. 2005;151:171–5.
42. Snyder SJ, Karzel RP, Del Pizzo W, et al. SLAP lesions of the shoulder. *Arthroscopy*. 1990;6:274–9.

43. Enad JG, Kurtz CA. Isolated and combined Type II SLAP repairs in a military population. *Knee Surg Sports Traumatol Arthrosc.* 2007;15:1382–9.
44. Enad JG, Gaines RJ, White SM, et al. Arthroscopic superior labrum anterior–posterior repair in military patients. *J Shoulder Elbow Surg.* 2007;16:300–5.
45. Kim SH, Ha KI, Kim SH, et al. Results of arthroscopic treatment of superior labral lesions. *J Bone Joint Surg Am.* 2002;84:981–5.
46. Kurtz CA, Gaines RJ, Enad JG. Arthroscopic management of superior labrum anterior and posterior (SLAP) lesions. *Oper Tech Sports Med.* 2005;13:157–61.
47. Morgan CD, Burkhart SS, Palmeri M, et al. Type II SLAP lesions: three subtypes and their relationships to superior instability and rotator cuff tears. *Arthroscopy.* 1998;14:553–65.
48. White DW, Wenke JC, Mosely DS, et al. Incidence of major tendon ruptures and anterior cruciate ligament tears in US Army soldiers. *Am J Sports Med.* 2007;35:1308–14.
49. Peliton J, Ellingson CI, Sekiya JK. Pectoralis major muscle ruptures. *Oper Tech Sports Med.* 2005;13:162–68.
50. Peliton J, Carr DR, Sekiya JK, et al. Pectoralis major muscle injuries: evaluation and management. *J Am Acad Orthop Surg.* 2005;13:59–68.
51. Komurcu M, Yildiz Y, Ozdemir MY, et al. Rupture of the pectoralis major muscle in a para-trooper. *Aviat Space Environ Med.* 2004;75:81–4.
52. Warne WJ, Whitaker DC. Pectoralis major tendon avulsion from rappelling. *Mil Med.* 2004;169:151–4.
53. Antosh IJ, Grassbaugh JA, Parada SA, et al. Pectoralis major tendon repairs in the active-duty population. *Am J Orthop.* 2009;38:26–30.
54. Harrison AK, Flatow EL. Subacromial impingement syndrome. *J Am Acad Orthop Surg.* 2011;19:701–8.
55. Tashjian RZ. Epidemiology, natural history, and indications for treatment of rotator cuff tears. *Clin Sports Med.* 2012;31:589–604.
56. Matsen FA, Titelman RM, Lippitt SB, et al. Rotator cuff. In: Rockwood CA, Matsen FA, Wirth MA, et al., Editors. *The shoulder.* Philadelphia: WB Saunders; 2004. pp. 795–878.
57. Neer CS. Impingement lesions. *Clin Orthop.* 1983;173:70–7.
58. Lehman C, Cuomo F, Kummer FJ, et al. The incidence of full thickness rotator cuff tears in a large cadaveric population. *Bull Hosp Jt Dis.* 1995;54:30–1.
59. Yamanaka K, Fukada H. Pathologic studies of the supraspinatus tendon with reference to incomplete partial thickness tear. In: Takagishi N, Editor. *The shoulder.* Tokyo: Professional Postgraduate Services; 1987. pp. 220–4.
60. Sher JS, Uribe JW, Posada A, et al. Abnormal findings on magnetic resonance images of asymptomatic shoulders. *J Bone Joint Surg Am.* 1995;77:10–5.
61. Yamamoto A, Takagishi K, Osawa T, et al. Prevalence and risk factors of a rotator cuff tear in the general population. *J Shoulder Elbow Surg.* 2010;19:116–20.
62. Mall NA, Lee AS, Chahal J, et al. An evidence-based examination of the epidemiology and outcomes of traumatic rotator cuff tears. *Arthroscopy.* 2013;29:366–76.
63. Solomon DJ, Provencher MT, Bell SJ, et al. Arthroscopic rotator cuff repair in active duty military personnel: a young cohort of patients with rotator cuff tears. *Oper Tech Sports Med.* 2005;13:136–42.
64. Lawrence RC, Felson DT, Helmick CG, et al. Estimates of the prevalence of arthritis and other rheumatic conditions in the United States. Part II. *Arthritis Rheum.* 2008;58:26–35.
65. Rivera JC, Wenke JC, Buckwalter JA, et al. Posttraumatic osteoarthritis caused by battle-field injuries: the primary source of disability in warriors. *J Am Acad Orthop Surg.* 2012;20 Suppl 1:S64–9.
66. Kuklo TR, Heekin RD, Temple HT, et al. A review of total joint replacement in active duty soldiers. *Mil Med.* 1997;162:201–4.
67. Fehring EV, Mikuls TR, Michaud KD, et al. Shoulder arthroplasties have fewer complications than hip or knee arthroplasties in US veterans. *Clin Orthop Relat Res.* 2010;468:717–22.

Chapter 8

Elbow, Wrist, and Hand Injuries

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Introduction

There is a paucity of literature on upper extremity injuries in the military, although it is known that these injuries not only significantly affect activities of daily living and military performance but also negatively affect psychosocial well-being, readiness for duty, and morale [1, 2].

Upper extremity injuries in the military can also be categorized into non-battle injuries and battle-related injuries. These injuries, as sequelae of occupational hazards of being in the military, are related to an increase in activities that cause injury and obviously exposure to hazards such as improvised explosive devices (IEDs) and enemy (as well as friendly) fire. The severity, cause, treatment, and sequelae of non-battle injuries are similar enough to nonmilitary injuries to be able to make practical comparisons, whereas battle-related injuries and their management have led to a creation of a new literature genre. However, the epidemiology of injuries that are seen in the nonmilitary population may differ from that reported historically in the nonmilitary literature. The goal of this chapter is to elucidate the epidemiology, causes, and potential treatments for these injuries, both non-battle injuries and battle-related injuries, with respect to the existing body of literature.

Differences in the deployed and nondeployed health setting have been studied. A retrospective investigation of medical surveillance data comparing the years 1998–2001 and then 2002–2006 demonstrated a 3 % increase in upper extremity injuries, most notably amputations, burns, brachial plexus lesions, and radial and

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123

ulnar nerve lesions. In addition, the rates of increase differed among the different services. Interestingly, in the Army, there were fewer dislocations, fractures, ganglion cysts, and rotator cuff/shoulder syndromes [3].

In the nondeployed health setting, according to Defense Medical Surveillance System (DMSS) data from 2006, in the US military, the rate of nondeployment hospitalization for upper extremity injuries was 532 out of a total of 3331 hospitalizations for injury, with 13.5% of total hospitalizations for shoulder, 1.3% for elbow/forearm, 0.7% for wrist, and 0.5% for hand injuries. The rate of ambulatory patient visits for injury was 98,489 out of a total of 537,155 visits, with 12.3% of the total visits for shoulder, 2.4% of visits for elbow/forearm, 2.3% of visits for wrist, and 1.4% of visits for hand [4].

In the deployed setting, there is also a difference between non-battle injuries and combat-related injuries. Non-battle injuries by and large make up the greatest proportion of medical evacuees out of theater. Out of the 9530 evacuated for non-battle injury in Operation Iraqi Freedom (OIF) from 2003 to 2006 and out of the 1515 evacuated for non-battle injury (NBI) in Operation Enduring Freedom (OEF) from 2000 to 2006, 34.5 and 36.1%, respectively, of these transports were because of upper extremity injury, and further more, 12.9 and 12.3%, respectively, of the patients were evacuated because of hand and wrist injuries [5]. Ongoing attempts are being made to decrease the number of patients being evacuated for further evaluation; an early analysis of the Army's telemedicine program determined that out of the 170 patients who would have otherwise been evacuated for orthopedic consultations, surgery was recommended in only 25%, and evacuation was recommended in only 16% [6].

In lieu of the frequency of non-battle injuries sustained in theater and also pre-deployment, the question also arises whether these injuries affect the deployment status of soldiers. In one analysis of personnel about to deploy to OIF, 158 soldiers with orthopedic injuries 3 months before deployment were followed longitudinally to determine their deployability status. Of the personnel with upper extremity injuries, that is, 35 of the 158 soldiers, 17, or 48.6%, were fit to deploy on time, and these were the most favorable compared to lower extremity and spine injuries [7].

Part 1: Peacetime/Non-battle Injuries

Distal Biceps Tendon Rupture [4]

Closed midsubstance ruptures of the biceps brachii are more commonly reported in US military static line parachute jumps than in the general population [8]. A review of military static line jumps over a 1-year period showed a 7.4% rate of arm and a 2.6% rate of elbow injuries [9]. In a review of more than 242,000 jumps, of the 2000 reported injuries, 4.4% were intrasubstance tears of the biceps brachii [8].

Biceps brachii rupture occurs most commonly when the jumper exits the aircraft with the static line medial to his arm. As he descends and adducts his arms, the static

line tightens around his arm causing a sudden compression, forced abduction, and external rotation force [10].

This injury is generally treated with operative repair, which has been shown to return elbow flexion strength to approximately 76.5–79% of the contralateral side [10, 11].

Prevention of biceps brachii rupture in someone about to make a static line parachute jump involves listening to the instructions from the jumpmaster and making a tight exit from the aircraft with hands clasped onto the equipment and the static line to the outside of the body [12]. Even so, although this is a traumatic event, preexisting degenerative changes to the biceps may place it at an increased risk for rupture.

Preexisting degeneration can be caused by modifiable external risk factors, including nicotine and anabolic steroid use. In a study of bilateral biceps tendon ruptures, those affected had a higher rate of nicotine and anabolic steroid abuse than the general population [13]. Since nicotine exposure is so prevalent in the military, personnel may be at greater risk for biceps ruptures than the general population. Worldwide, the prevalence of cigarette smoking in the military is approximately 41% among 18–25-year-olds, compared to 28% in the general population of males of a similar age [14]. The use of alternative forms of tobacco, such as cigars and smokeless tobacco, has been shown to be increasing among young military recruits [15]. Also, in a recent survey study of US active duty, reserve, and National Guard personnel, 17.3% of the population reported the use of bodybuilding supplements [16]. Continued education about the adverse health effects of nicotine and certain bodybuilding supplements and cessation strategies should be offered to military service members. As suggested by Forgas et al., these efforts would be greatly improved by concurrently decreasing the availability of these products on military installations [5, 15].

Fractures of the Forearm

The incidence of forearm fractures in the USA by the National Hospital Ambulatory Medical Care Survey in 1998 was 44% of the 1,465,874 hand and forearm fractures reported by ICD-9 coding [17].

Stress fractures of the forearm are a rare injury often seen in young, healthy athletes and soldiers who have high functional demands of both upper extremities [18]. Two case series of military recruits participating in rifle drill training demonstrated 1 and 5.6% incidences of forearm stress fractures [18, 19]. Kuo et al. reported that 91.7% of the fractures involved the dominant forearm and 50% sustained bilateral stress fractures, with only one reported radius fracture [18]. These recruits were participating in a 4–6-month training with a 5-day training schedule, which included repetitive rotations of the 6.8-kg rifle in the air at a rate of 100 times per minute for 5 h a day. The duration of daily training was increased 2 weeks before they participated in official performances. In addition, the recruits were expected to perform an average of 100–200 push-up exercises per day [18]. There is often a delay in diagnosis because the symptoms disappear or decrease during rest, and radiographs

do not usually present positive findings until 3 weeks after symptom onset [19]. The study by Kuo et al. showed a mean duration of symptoms of 4.2 weeks (range: 2–9 weeks) before accurate diagnosis [18].

The cause of ulnar stress fractures (Fig. 8.1a and b) is thought to be secondary to repetitive excessive pronation of the forearm while lifting a heavy rifle and a sudden increase in the length of training per day [19]. The recruits also did not stop training after the onset of pain, particularly in their dominant forearm. It was therefore postulated that bilateral stress fractures are not surprising since recruits will adapt to pain in their dominant forearm by supporting more of the rifle's weight with their nondominant hand and shifting their body weight to the nondominant hand side during push-up exercises. In this manner, they may have caused the subsequent stress fracture of the nondominant ulna [19].

All the stress fractures described in the two studies were treated nonoperatively. The patients with complete stress fractures were treated with cast immobilization and subsequent continued activity restriction, and the patients with normal or stress reactions on their radiographs simply stopped rifle drill training and vigorous forearm exercises for 6 weeks [18, 19].

Several recommendations have been proposed to decrease the incidence of forearm stress fractures. Most importantly, military commanders and recruits should be educated about this injury in order to set up a proper training schedule and encourage early diagnosis and treatment. It is recommended that the training protocol be adjusted to (1) use a lighter substitute to replace the rifle in the initial 6 weeks of training; (2) gradually advance the duration of training hours per day in a proper

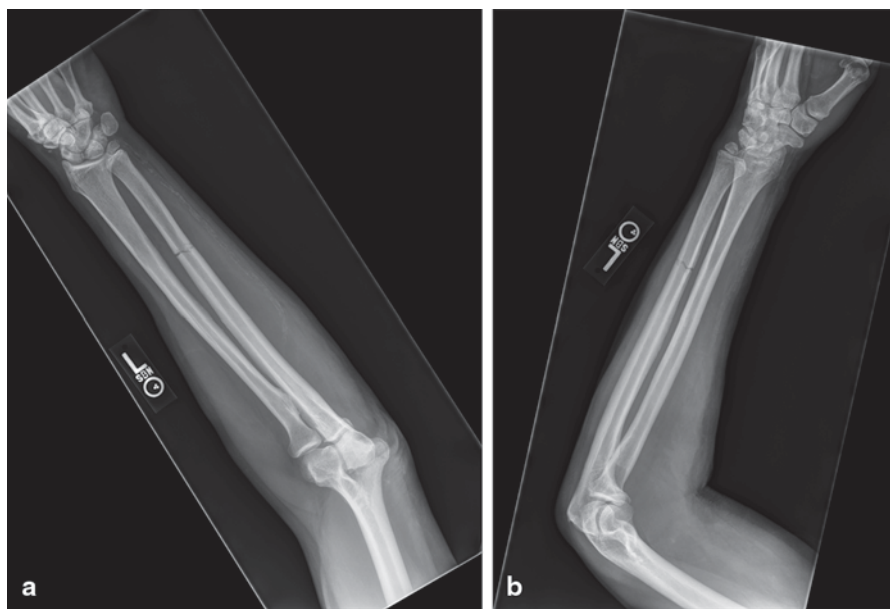


Fig. 8.1 **a** Posteroanterior and **b** lateral radiographs of the forearm with ulnar stress fracture

sequence; and (3) extend the time evenly, allocate the training load during the intensive training period, and extend the duration of this period [19]. In addition, a high index of suspicion for a forearm stress fracture should prompt ordering of a bone scan, which shows pathologic uptake within 24 h in 95 % of patients after a stress injury to a bone [20].

It is also important to screen patients early who may have increased risk factors for a stress injury. Although all the previously mentioned studies reported on male subjects, under military conditions, the female-to-male ratio for stress fractures is 4–6:1, which is double the rate seen in athletes [21]. It is hypothesized that women's bones are more prone to stress with increased load carriage. Female soldiers who present with stress fractures should be screened for vitamin D levels and a thorough menstrual history should be obtained as well. The female athlete triad, the combination of disordered eating, amenorrhea, and osteoporosis, may predispose a female soldier to the development of a stress fracture. However, in a recent study of 423 active duty women, no subject exhibited the full female athletic triad [22]. In addition, some studies have shown that sustained use of a progesterone-based contraceptive may decrease the bone mineral density in women, particularly in those engaged in high levels of physical activity [23].

Olecranon Bursitis

Wasserzug et al. reviewed two 18-man infantry platoons, with soldiers aged 19–20 years old, during their basic military training [24]. Over a period of 10 months, nine soldiers from one platoon developed septic olecranon bursitis, which was defined as an extensive local infection with intense peribursal cellulitis or infected skin lesion that was accompanied by systemic symptoms or signs of a fever of $>37.7^{\circ}\text{C}$, chills, or leukocytosis of more than 10,000 leukocytes/ mm^3 in the peripheral blood. The authors reported a 3.86 (CI, 1.1–13.6; $p=0.04$) relative risk of developing septic olecranon bursitis in soldiers who had moderate to severe trauma to the skin overlying the elbow. They suggested that this trauma served as the “port of entry” for the bacteria. *Staphylococcus aureus* carrier state was not statistically significant for the development of septic olecranon bursitis, although the rate of *S. aureus* isolation in the two platoons was 81 %, compared with 20–37 % in the general population. After the outbreak in septic olecranon bursitis, both platoons in the aforementioned cohort were treated with nasal mupirocin ointment for local control and nasal eradication of *S. aureus*. After this 5-day treatment, no further cases of septic olecranon bursitis were reported.

Despite the lack of statistical significance between carrier state and clinical infection, the absence of reported cases after nasal mupirocin treatment and the fact that the severe infections were associated with a specific *S. aureus* clone support a potential contribution of *S. aureus* carrier status. Furthermore, 62 % of the isolates were related to other isolates suggesting a transmission due to close contact and shared equipment during infantry training [24]. In addition, soldiers should be educated on the Army standards of field hygiene that include hand-washing with soap and water after handling any item that can potentially transfer germs and frequent

bathing to decrease pathogens. Also according to regulations, during field training exercises, all service members must bring their own toilet articles such as soap, shampoo, washcloths, towels, toothbrush, dental floss, fluoride toothpaste, talcum powder, and foot powder; furthermore, they should not share these items to prevent the spread of infections [25]. In addition, as severe skin injury is identified as a significant risk factor for septic olecranon bursitis, and the morbidity is primarily seen in the dominant elbow, which carries the brunt of the weight of a soldier's weapon, soldiers should be encouraged to use elbow pads which are part of the standard issue combat equipment [24].

Medial and Lateral Epicondylitis

Lateral and medial epicondylitis are common insertional tendinopathies at the elbow affecting the origin of the extensor carpi radialis brevis and flexor carpi radialis and pronator teres, respectively. An epidemiological study of approximately 12 million US military service members demonstrated an unadjusted incidence rate of 2.98 per 1000 person-years for lateral epicondylitis. This was compared to 0.81 per 1000 person-years for medial epicondylitis. Increasing age was associated with a higher rate of both lateral and medial epicondylitis. Although lateral epicondylitis was diagnosed more frequently in women than in men (adjusted incidence rate ratio of 1.22 [95% CI 1.19–1.26]), there was no difference in the occurrence of medial epicondylitis between men and women [26].

Both of these tendinopathies are initially treated with nonoperative management to include splinting, occupational therapy, and numerous types of injections, to include corticosteroids, autologous blood, and botulinum toxin [26]. Surgical options include some form of tendon debridement, either done through an open incision or arthroscopically. However, the majority of cases of lateral epicondylitis resolve after approximately 1 year of conservative treatment, with or without treatment [27]. Therefore, it is important to counsel both the active duty service members and their chain of command about the expectations and duration of treatment, as nonoperative management may affect their ability to participate in required military duties for an extended period of time.

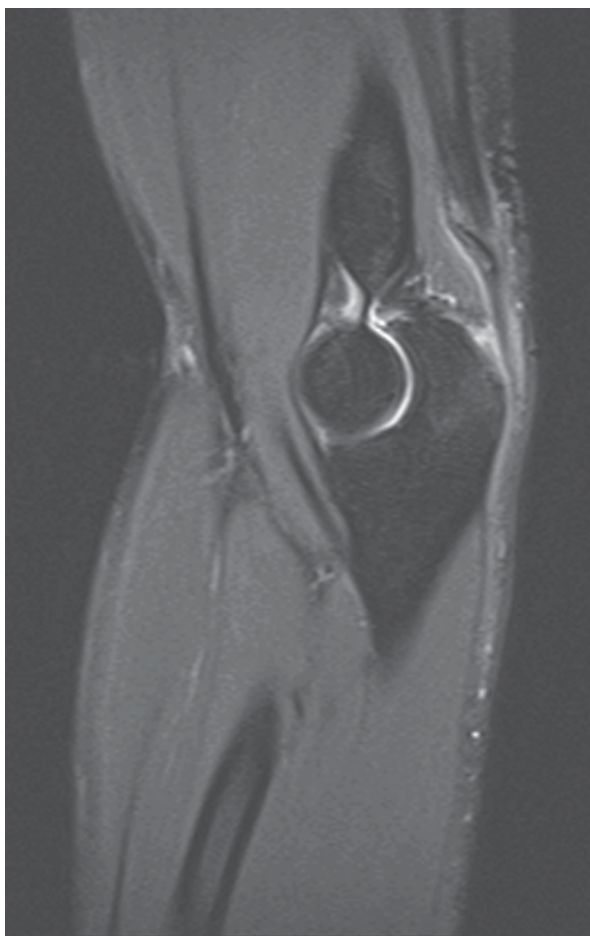
Lateral and medial epicondylitis have been associated with both current and former smoking [28]. It is hypothesized that nicotine's vasoconstrictive properties may place tendons at a higher risk for injury and slow or prevent healing. As suggested earlier, a combined strategy of education and decreased access to low-cost tobacco products may help reduce the prevalence of nicotine use within the military population. These tendinopathies have also been associated with occupational demands combining repetitive and forceful activities, and the risk of developing lateral epicondylitis was more common in patients who had a longer exposure to these activities [28]. This association supports the hypothesis that medial and lateral epicondylitis are caused by repeated microtrauma at the origin of the common flexor and extensor tendons. Once again, it is a combined effort of the patients and their chain of command in order to find ways for the service members to modify their physical load factors and decrease the repetitive activities about their elbow.

Triceps Tendon Rupture

Anabolic steroid abuse was suspected as a contributing factor in a midsubstance rupture of the triceps tendon reported in a 35-year-old active duty soldier by Stanard and Bucknell [29]. The tear, which was 2 cm proximal to the triceps insertion into the olecranon, was sustained during a hyperflexion injury while the soldier was weight lifting. The injury occurred approximately 3 weeks after the patient had received the last in a series of six separate steroid injections for olecranon bursitis over a 1-year period. The soldier had also reported a history of anabolic steroid abuse ending approximately 6 months earlier.

In general, as tendon is the strongest link in the musculotendinous chain, excessive stress placed against the contracted triceps muscle usually results in an olecranon fracture, as opposed to a tendon rupture (Fig. 8.2) [29]. Therefore, it is suspected that both anabolic steroid abuse and local steroid injections are likely

Fig. 8.2 MRI image of low-energy triceps rupture



to cause damage to an otherwise normal tendon. Similar to the biceps tendon ruptures, this case highlights the need to screen soldiers for anabolic steroid abuse. The authors also recommend caution in using local steroid injections to treat inflamed tissues in a population of strength athletes who are placing high demands on their muscles and tendons [29].

Scaphoid Fractures

The incidence of scaphoid fractures in the general population in the USA, as estimated by data drawn from the National Electronic Injury Surveillance System (NEISS) from 2002 to 2006, was 21,481 fractures among 909,309 total wrist fractures, with an estimated incidence of 1.47 fractures per 100,000 person-years [30]. It is not surprising, then, as scaphoid fractures are found in the highest rates in young active males, that the incidence in a military population is higher. This is confirmed by a Defense Medical Epidemiology Database (DMED) estimate demonstrating that the incidence is in an order of magnitude higher at 1.21 per 1000 person-years [31]. At Tripler Army Medical Center, from 2001 to 2003, the incidence was 43 cases per 100,000 personnel per year [32].

The mechanism of injury is classic, such as fall on the outstretched hand or direct blows to the wrist such as those sustained while pugil stick fighting. In the military system, scaphoid fractures are referred through unit medical clinics and battalion aid stations by nonspecialists. Given the high incidence and the potentially devastating complications of a missed injury, detection and referral algorithms have been proposed based on the clinical scenario [32].

In addition, the proposal for percutaneous screw fixation treatment for nondisplaced acute scaphoid fractures has come from the military as well. Bond et al., in 2001, proposed in a prospective, randomized study that fixation of these scaphoid fractures with a percutaneous cannulated screw resulted in shorter time to clinically apparent union and earlier return to military duty (8 weeks as opposed to 15 weeks) than if treating the fractures with cast immobilization [33]. This is important considering that return to duty has many implications for deployment, the individual's career, and the needs of the military.

Hand and Wrist Soft Tissue Injuries

Hand and wrist soft tissue injuries encompass a wide variety of diagnoses, encompassing overuse and acute injuries classified under "sprains." According to DMSS data, in 2006, the number of military visits related to "sprains and strains" of the hand and wrist were 17,395, while visits related to contusions were 12,385. A total of 11,815 visits were related to overuse injuries of the hand and wrist [4].

Specifically, the incidence of de Quervain's tenosynovitis in the military has been described. Via the DMED, an ICD-9 query for the diagnosis, 727.04, from the

years 1998–2006 has revealed 11,332 cases in 12,117,749 person-years. Women have a significantly higher rate of de Quervain's tenosynovitis at 2.8 cases per 1000 person-years compared to men at 0.6 per 1000 person-years. In addition, it was found that personnel of age greater than 40 had a rate of 2.0 per 1000 person-years compared to 0.6 per 1000 for personnel under 20 years, as well as a racial difference, which demonstrated that blacks were affected at 1.3 per 1000 person-years compared to whites at 0.8 [34].

Another disease entity described in the literature with respect to the military is carpal tunnel syndrome (CTS). In an epidemiological study of the US Navy from 1980 to 1988, it was found that the incidence was 493 cases per 4,095,708 person-years in men and 90 cases in 365,668 person-years in women. The incidence was higher in women, especially in white women. Occupations with higher standardized incidence ratios included aviation-support equipment technician, engineman, hull-maintenance technician, boatswain's mate, and machinist's mate. In women, occupations with significantly high standardized incidence ratios included boatswain's mate, engineman, hospital corpsman, ocean-systems technician, and personnelman [35].

The overall incidence of CTS in the US military population according to an ICD-9 code (354.0) query of DMED data from 1998 to 2006 is 3.98 per 1000 person-years, in a population of 12,298,088 person-years. This is consistent with previous epidemiological studies of certain populations or working groups reporting incidences between 1.5 and 3.5 per 1000 person-years [36–40]. Again, females have a higher incidence with an adjusted incidence ratio of 3.29, and enlisted personnel and senior officers had an increase in incidence, suggesting that perhaps here there was an occupational relationship [41, 22].

A more recent analysis written in 2011 with stricter means of capturing patients with CTS demonstrated a declining incidence during the period from 2000 to 2010 from 2.71 to 1.37 per 1000 person-years with a crude overall incidence rate of 1.71 per 1000 person-years. This reflects an incidence similar to the general population. The incidence is thought to be an underestimate, however, given that the analysis required two outpatient visits with this diagnosis rather than one. However, again it was shown that females have a higher incidence, as well as personnel who were older. Other occupational risks included being in the Air Force and in health care and administrative occupations [42].

Specifically, personnel who perform activities involving repetitive bending and twisting of the hands and wrists and use vibrating tools are known to be at a relatively high risk for CTS. The incidence of this problem among dental personnel is described by Lalumandier et al. in a survey study identifying the likelihood of having symptoms of CTS. By survey analysis, 25.4% were determined to indicate a high probability of CTS. Further more, of the 18 dental job specialties, dental therapy assistants and dental hygienists had the highest prevalence of CTS, 73 and 57%, respectively [43]. Further more, another study using actual clinical and electrodiagnostic data in a sampling of personnel has determined that at baseline the incidence of median nerve abnormalities among dental personnel even prior to training is higher than the 5%

reported in healthy populations but less than the previously mentioned 25% [44]. Another study in a different sample determined that even after training there was no shift in the prevalence of electrodiagnostic abnormalities of the median nerve [45].

Injuries to the Hand

Injuries to the hand are very common and are often the cause of evacuation out of theater. These injuries are not necessarily due to battle injuries; in fact, in one study of isolated hand injuries in the British military, in a 6-year period, only 9% were from battle. From this 6-year period, 6337 medical cases were evacuated back to the UK, 6.5% of which were identified as hand injuries. Half of the injuries involved fractures, and 73% of the patients required surgery. In the cases of personnel requiring surgery, 1/3 of them had surgery in a deployed setting, and of these patients who had primary nerve or tendon repairs tended to do worse than their counterparts who had surgery after evacuation in a delayed fashion [46]. Another British study described hand injuries at British Military Hospital in Shaibah, 2004, where 478 of 5614 patients (8.5%) had hand injuries. Most of the hand traumas were due to non-combat injury (92%), specifically soft tissue injuries. These traumatic injuries occurred most frequently in males, manual workers, combat soldiers, and engineers/mechanics. The authors also found that many patients required periods of restricted duty (52%) and some required evacuation (8%), in particular, those patients who required surgery [47].

The US military reports similarly high rates of noncombat-related hand traumas. An analysis of 2007–2009 data from Ibn Sina Hospital in Baghdad, Iraq, demonstrates that of 7520 patients seen, 331 patients had hand injuries, 74 of which required evacuation. The hand trauma mechanisms were mostly related to work accidents, specifically injuries sustained while closing vehicle doors, hatches, and turrets [48].

Hand Fractures

One study out of the 121st Combat Support Hospital in Yongsan, South Korea, describes the incidence of metacarpal fractures. A total of 37% of musculoskeletal visits to this hospital each week are hand injury related. Between 2006 and 2007, 66 patients presented to the occupational therapy clinic with metacarpal fractures. A high proportion of the patients were single males on their first duty assignments and the mechanism of injury was from striking a person or object out of anger [49]. This is not unlike the demographic and mechanism of these aptly named boxer's fractures in the general population. Similarly, in men, small finger metacarpal fractures are associated with social deprivation, as the mechanism of injury is often assault or punch injury [50].

Overuse injuries with respect to osseous aspects of the hand are possible as well as manifested in stress fractures. Push-ups can be a source of potential microtrauma that can lead to carpal and metacarpal stress fractures, as noted in a case report [51].

Hand Soft Tissue Injuries

As much as the majority of hand injuries sustained in the military in a noncombat setting are not fractures but soft tissue injuries, specific hand soft tissue injuries are not very well described. One study out of Tripler Army Medical Center describes collateral ligament injury of the thumb metacarpophalangeal (MCP) joint. In a period of 5 years, 56 patients presented with thumb MCP joint instability, and 18% had a radial collateral ligament injury. The mechanism of injury for radial collateral ligament insufficiency was most likely an axial load injury, whereas for ulnar collateral ligament insufficiency, the mechanism of injury was most likely an abduction–adduction moment. As a whole, the patients with radial collateral ligament injuries were younger and more of them required surgery compared with those in the group presenting with ulnar collateral ligament injuries [52] (67 vs. 40 %).

Part 2: Combat Trauma

Epidemiology of Blast Trauma

The percentage of personnel surviving battlefield injuries continues to increase, most of which is attributable to improvements in protective equipment, evacuation systems, and modern medical treatment. Protective equipment advances have prevented significant amounts of damage due to penetrating abdominal trauma, but the feasibility of protecting extremities to include the lower arm and hand is not readily apparent [53]. Approximately 70% of battlefield injuries are to the extremities [54]. A lot of these injuries result in high-energy wounds caused by IEDs, mortars, rockets, rocket-propelled grenades, and guns of various types [55, 56]. The wounds are often contaminated and the zone of injury is very large. In case of a high-energy wound, the concern is control of infection, management of soft tissue, timing of definitive fixation, attempting limb salvage, and timing of amputee management [56]. In general, management of these injuries involves meticulous early debridement, control of infection, and wound management with delayed reconstruction [56, 57].

A 2007 analysis of extremity injuries out of the Joint Theater Trauma Registry (JTTR) as a result of combat trauma sustained in OIF and OEF found that from 2001 to 2005, 1281 soldiers sustained 3575 wounds to include 915 fractures; of these, 75 % were from explosive injury; 461, or 50 % of the fractures, were of the upper extremity, with hand fractures being the most common at 36 % [58]. In an analysis of the US Navy/Marine Corps Combat Trauma Registry (CTR) for patients who received treatment for combat wounds in Iraq from 2004 to 2005, out of 665 extremity combat-wounded patients, 261, or 39%, sustained injuries to the upper extremities, and 181, or 27%, sustained injuries to both upper and lower extremities. In this analysis, upper extremity wounds were less likely to be coded as serious or fatal by Abbreviated Injury Scale (AIS) scoring [59].

Burn Injuries

Burn injuries comprise 5–20 % of modern combat injuries [60]. In the USA, combat casualty burns are admitted to the US Army Burn Center at Brooke Army Medical Center. From March 2003 through June 2005, 299 OIF/OEF combat casualty burn patients were admitted; of these, 285 survived injury. Of these, 221 (78 %) sustained burn injury to at least one hand, of which 143 (65 %) recovered and returned to duty [61]. In order to combat this, an All Army Activity (ALARACT) message emphasizing the importance of hand protection was disseminated in December 2005, but its efficacy is questioned [62].

Nerve Injuries

Another specific type of injury to note is that of the peripheral nerves. In the British literature, one epidemiological study found 261 peripheral nerve injuries in 100 service members. The most common upper extremity nerve injured was the ulnar nerve. A total of 164 of the injuries sustained were a result of explosions, and 213 were associated with open wounds; in fact, 50 patients sustained major tissue loss [63].

Early Management

In the acute setting, management of these battle injuries entails time-tested principles of early and aggressive debridement, as first widely agreed upon at the Inter-Allied Surgical Conference in 1917. It was at this time that the term “debridement” came into being as meaning incision accompanied by excision of the damaged underlying tissue. In general, this entails excision of the skin margin, generous extension of the wound, exploration through all layers, and excision of damaged muscle [64].

It is important to note that most of these injuries are not isolated. At least 60 % of patients with ballistic trauma to the hand have a concomitant injury elsewhere [65]. After adequate evaluation and prioritization, hand and upper extremity wounds are assessed and managed surgically. The goals of the initial surgery include preservation of vital structures, restoration of viability, and prevention of sepsis. This entails conservative debridement, relief of evolving hematomas, reduction of fractures, and revascularization as feasible. Wounds should be left open. The second surgery should continue to follow principles of maximum preservation of vital structures, and now affords a second look to assess for viability and to set the stage for further reconstructive procedures [66].

There are many similarities between the treatment of blast injuries sustained in the combat environment and current civilian damage control orthopedics. As

in civilian traumas, the early administration of antibiotics is key to decreasing infection rates in open fractures and amputations. A key distinction in the deployed environment is that it is important to use broad-spectrum antibiotics for coverage against gram-positive, gram-negative, and anaerobic species [67]. High doses of IV penicillin or, alternatively, erythromycin, chloramphenicol, or a cephalosporin have been recommended to decrease the risk of gas gangrene, which is caused by anaerobic *Clostridium* species [68]. It is also recommended that all patients receive tetanus toxoid with the addition of antitetanus immunoglobulin for those with an unknown immunization status. US military predeployment screening ensures that all active duty soldiers are up-to-date with their immunizations—to include tetanus [69]. In high-grade open fractures, particularly those with large cavitations, the use of a polymethylmethacrylate antibiotic bead pouch is a proposed technique to deliver a high concentration of antibiotics, decrease wound dead space, and reduce bone desiccation until wound coverage is completed.

Another vital aspect of early wound management and evacuation of patients is the advent of negative pressure wound therapy. Many studies have previously found negative pressure wound therapy to be very beneficial as an adjunct to managing open, complex wounds due to better wound granulation, wound contraction, improved control of wound exudates, decreased wound edema, reduced skin maceration, and improved pain management [70–74]. After a study in which 31 enrolled patients with 40 separate wounds flying with such devices had good, predictable outcomes with no increases in wound complications or increases in aircrew workload, these devices are ubiquitous in the management of these wounds at the outset [75]. In fact, a gauze-based, topical, negative-pressure dressing system can be used as a functional splint more efficiently than standard dressings and plaster splints [76].

Negative pressure therapy is used because early wound coverage is often unfeasible due to combat environment and transfer time. In a series of open fractures, Gustilo and Anderson showed a decrease in infection rate from 83 to 18% when the fractures were covered within 10 days of injury [77]. Unlike civilian injuries, the large amounts of nonviable tissue and deeply impacted debris associated with these blast injuries typically cannot be treated with early wound coverage.

Debridement surgeries should focus on the curettage of contaminated bone ends to remove foreign material, along with the removal of all nonmetallic foreign material and small, devitalized bone fragments, and on the excision of nonviable fat, muscle, and fascia back to healthy tissue [68]. Irrigation and debridement procedures are generally carried out every 24–48 h, and the wound is left open until it is clean and granulation tissue has appeared [67]. Therefore, early stabilization using Kirschner wires, external fixators, or plaster of paris remains the mainstay of fracture care. A recent retrospective review of US military personnel treated with internal fixation within the theater of combat operations reported only one postoperative infection that occurred after a revision internal fixation procedure [24]. However, the authors acknowledged that the treated injuries were less severe than those seen in our current conflicts. Because adequate surgical debridement to allow for definitive fixation and wound closure is not typically available within the

combat environment, expedited evacuation to higher echelons of medical care is paramount. Lin et al. reported an average evacuation time of 8.0 days for US soldiers with open fractures [69]. Wound coverage was achieved within an average of 12 days post injury.

Finally, outside of prevention of infection and preparation for definitive wound coverage, early heterotopic ossification (HO) prophylaxis is being taken more into consideration. Nonsteroidal anti-inflammatory medications have not been shown to provide prophylaxis against HO following surgical treatment of elbow traumas [78]. Radiotherapy delivered within 72 h of surgery has shown to be effective in the decrease of HO development at the elbow [79]. Unlike civilian traumas, several contraindications exist to the use of radiotherapy for combat-related injuries; severe systemic polytraumas, open and contaminated wounds requiring serial debridements, and fractures or spine injuries requiring operative stabilization and fusion [80].

Upper Extremity Reconstruction

Following the acute injury phase, when the patient has reached his or her destination of definitive care, reconstruction of the upper extremity commences in the subacute period. Case series and consensus agreements report on the techniques and methods of reconstruction with varying success rates. Many patients, because of the extensive soft tissue wounds and expansiveness of the zone of injury, require complex soft tissue reconstruction that entails anything from a split-thickness skin graft to free tissue transfer or any combination of the above.

Kumar et al. reported a series of 26 soft tissue transfer cases, of which six were free tissue transfers, all treated via the Bethesda limb salvage protocol. In the subacute period, this entails radical debridement and irrigation of all wounds every 48–72 h until the wounds appeared clinically clean and viable. In between washouts, negative pressure therapy (wound vacuum-assisted closure (VAC) therapy, KCI, San Antonio, TX) is applied to all the extremity wounds until wound coverage or reconstruction. Flap reconstruction can commence when the wounds are clinically ready. In this series, all the patients were polytraumatized and underwent multiple prereconstructive washouts, and many of them (46%) had culture-positive wounds. The wounds were all in the upper extremity. The average time to flap reconstruction was 31 days, with a range of 9–131 days. The flap success rate was high with only one failure and this failure did not lead to amputation [81].

Since then, at Walter Reed National Military Medical Center/National Naval Medical Center in Bethesda, from 2003 to 2011, a total of 151 limb salvage procedures were performed with 75 upper and 76 lower extremity flaps. In the latter years (2009–2011), more upper extremity flaps (ratio 3:2) have been performed, with more free tissue transfers twice as common as pedicle flap reconstructions. The flap success rate for the entire period described was more than 95% [82]. One of the aforementioned flaps described in the literature was a contralateral radial forearm flow-through flap that simultaneously revascularized and provided soft tissue



Fig. 8.3 This is a 21-year-old active duty Marine Corps Corporal who sustained multiple penetrating and blunt trauma injuries after he was injured in a blast in Afghanistan. Among his many injuries, he sustained an open left upper extremity ulna fracture with forearm degloving injury. The clinical photo (b) demonstrates a large soft tissue injury to the ulnar side of his forearm with exposed tendons. The x-ray image (a) demonstrates an ulnar fracture with approximately 2 cm of segmental bone loss

coverage for a complex volar hand blast injury [83]. One such reconstruction case is described in Figs. 8.3 and 8.4. This particular patient underwent wound care per protocol and then received open reduction and internal fixation of his ulna fracture and anterolateral thigh free flap to achieve coverage of his large forearm wound.

Another report on free tissue transfer from Brooke Army Medical Center describes a series of eight patients that underwent four latissimus dorsi muscle flaps and four radial forearm fasciocutaneous flaps during OIF. Here the causes of the soft tissue defects were all from explosives except for one from a fall and another from a helicopter crash. All free flaps were successful, with only three flap-related complications requiring operative intervention [84].

Pedicled flaps also have a major role in upper extremity limb reconstruction. Advantages over free tissue transfer include vascular supply far away from the zone of injury, decreased incidence of donor site morbidity, and shorter operative times with less blood loss, which can be crucial in certain patients. One case report describes two successful cases of simultaneous pedicle flap coverage for forearm and hand open injuries. In these cases, an inferiorly based right superficial epigastric artery flap and an inferiorly based left superficial epigastric artery flap were used simultaneously in the first patient described, and a superiorly based superficial epigastric artery flap and a right superficial circumflex iliac artery flap were used in the second patient [85].

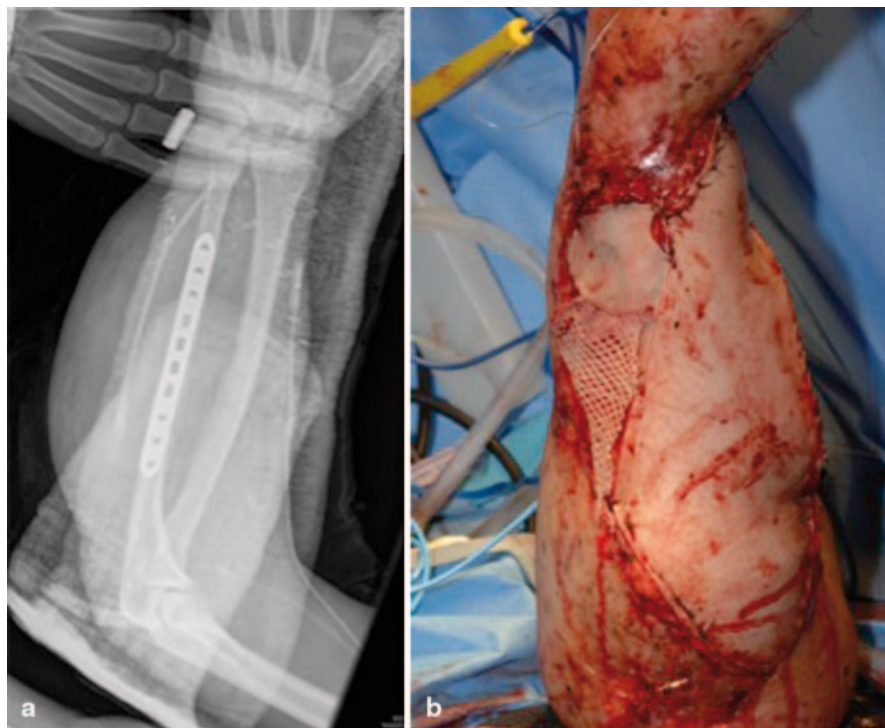


Fig. 8.4 After initial injury and battlefield tourniquet placement to his right upper and bilateral lower extremities, the patient was medically evacuated to the Role 3 medical facilities in Kandahar, Afghanistan, where an initial irrigation and debridement was performed on his right upper extremity. His forearm wound was packed and a splint was applied. The following day, the patient was transferred to the Role 4 medical facility at Landstuhl Regional Medical Center in Germany, where a second irrigation and debridement was performed and negative pressure wound therapy was started on his forearm. On 10 April, the patient was evacuated to the Role 5 medical facility in Bethesda, MD. He underwent subsequent irrigation and debridements to manage his wound until it was ready for his definitive procedure. Three and a half weeks after initial injury, he underwent open reduction and internal fixation of the ulna, with allograft bone grafting to address the bone defect, and anterolateral thigh free tissue transfer with microvascular anastomosis to the left forearm. The x-ray image (a) demonstrating his definitive fixation and a clinical photograph (b) of his definitive soft tissue coverage procedure are shown

Late Sequelae of Combat Trauma

The development of HO, as a late sequela of combat traumas, is coming more and more into the forefront of combat literature in terms of basic science research and clinical studies of patients who sustain severe soft tissue injuries via the high-energy mechanism typical of combat traumas. For example, the rate of HO formation in amputees is reported to be about 64%, with at least 19% of those who develop HO requiring additional surgical procedures for excision of the HO [86]. Alfieri et al.

suggest an algorithm for treating symptomatic HO beginning with a minimum of 6 months of conservative therapy to include physical therapy, pain medication, and selected injections and nerve ablations for HO associated with neuromas [87]. HO resection has traditionally been delayed for 12–18 months due to the concern for a higher recurrence rate that occurs for excisions done prior to adequate cortication and maturation of the ectopic bone [88]. However, early resection is thought to minimize contractures, muscle atrophy, and cartilage degeneration and to also allow for a more rapid functional recovery [89]. Elbow range of motion is particularly important within the US military. Army Regulation 40–501, Standards of Medical Fitness, requires elbow range of motion to be at least 100° of flexion to 15° of extension in active duty service members [90]. In a retrospective review of periarticular combat-related fractures, 97% of the elbows that developed HO were Hastings Class II, which means that they had functional limitation in flexion and extension and/or pronation/supination. After HO excision surgery with concurrent capsulectomy or lysis of adhesions, they reported a mean sustained gain of 47.2° of flexion–extension range of motion (range: 15–110°). Of the 43 surgical elbows, there were 6 episodes of recurrent arthrofibrosis [78].

Conclusions

Upper extremity injuries, from both battle and non-battle causes, cause significant morbidity among military personnel. Preventative measures to minimize the risks of injury and awareness and measures to decrease the magnitude of the injuries should be followed to ensure the maximization of troop utilization, and, most importantly, to protect and treat the individual. Further investigation continues to be done through epidemiological studies as well as outcome studies as the overseas conflicts wind down and the long-term sequelae from severe blast injuries continue to be elucidated.

References

1. Morse TF, Dillon C, Warren N, Levenstein C, Warren A. The economic and social consequences of work-related musculoskeletal disorders: the Connecticut Upper-Extremity Surveillance Project (CUSP). *Int J Occup Environ Health*. 1998;4(4):209–16.
2. Peake JB. Reflections on injuries in the military: the hidden epidemic. *Am J Prev Med*. 2000;18(Suppl 3):4–5.
3. Brininger TL, Antczak A, Breland HL. Upper extremity injuries in the U.S. military during peacetime years and wartime years. *J Hand Ther*. 2008;21(2):115–22, (quiz 123). doi:10.1197/j.jht.2007.10.010.
4. Jones BH, Canham-Chervak M, Canada S, Mitchener TA, Moore S. Medical surveillance of injuries in the U.S. Military descriptive epidemiology and recommendations for improvement. *Am J Prev Med*. 2010;38(1 Suppl):S42–S60. doi:10.1016/j.amepre.2009.10.014.

5. Hauret KG, Taylor BJ, Clemmons NS, Block SR, Jones BH. Frequency and causes of nonbattle injuries air evacuated from operations Iraqi freedom and enduring freedom, U.S. Army, 2001–2006. *Am J Prev Med.* 2010;38(1 Suppl):S94–S107. doi:10.1016/j.amepre.2009.10.022.
6. Blank E, Lappan C, Belmont PJJ, et al. Early analysis of the United States Army's telemedicine orthopaedic consultation program. *J Surg Orthop Adv.* 2011;20(1):50–5.
7. Frank AJ. Orthopedic injuries before combat deployment—will the soldiers be ready for combat when their unit is called upon? *Mil Med.* 2011;176(9):1015–8.
8. Wilson DJ, Parada SA, Slevin JM, Arrington ED. Intrastance ruptures of the biceps brachii: diagnosis and management. *Orthopedics.* 2011;34(11):890–6. doi:10.3928/01477447-20110922-25.
9. Neves EB, de Souza MN, de Almeida RMVR. Military parachuting injuries in Brazil. *Injury.* 2009;40(8):897–900. doi:10.1016/j.injury.2009.01.136.
10. Traumatic isolated closed rupture of the short head of the biceps brachii in a military para-trooper. *Knee Surg Sports Traumatol Arthrosc.* 2010;18(12):1759–61. doi:10.1007/s00167-010-1108-2.
11. Heckman JD, Levine MI. Traumatic closed transection of the biceps brachii in the military parachutist. *J Bone Joint Surg Am.* 1978;60(3):369–72.
12. Bricknell MC, Craig SC. Military parachuting injuries: a literature review. *Occup Med (Lond).* 1999;49(1):17–26.
13. Schneider A, Bennett JM, O'Connor DP, Mehlhoff T, Bennett JB. Bilateral ruptures of the distal biceps brachii tendon. *J Shoulder Elbow Surg.* 2009;18(5):804–7. doi:10.1016/j.jse.2009.01.029.
14. Nelson JP, Pederson LL. Military tobacco use: a synthesis of the literature on prevalence, factors related to use, and cessation interventions. *Nicotine Tob Res.* 2008;10(5):775–90. doi:10.1080/14622200802027123.
15. Forgas LB, Meyer DM, Cohen ME. Tobacco use habits of naval personnel during Desert Storm. *Mil Med.* 1996;161(3):165–8.
16. Jacobson IG, Horton JL, Smith B, et al. Bodybuilding, energy, and weight-loss supplements are associated with deployment and physical activity in U.S. military personnel. *Ann Epidemiol.* 2012;22(5):318–30. doi:10.1016/j.annepidem.2012.02.017.
17. Chung KC, Spilson SV. The frequency and epidemiology of hand and forearm fractures in the United States. *J Hand Surg Am.* 2001;26(5):908–15. doi:10.1053/jhsu.2001.26322.
18. Kuo C-L, Pan R-Y, Wu J-L, Huang W-S, Wang S-J. Stress fractures of forearm bones in military recruits of rifle drill training. *J Trauma.* 2009;67(4):742–5.
19. Wu J-L, Huang G-S, Wu C-C, Lee C-H, Wu S-S. Stress fracture of the ulna occurring in military recruits after rifle drill training. *Mil Med.* 2004;169(10):839–41.
20. Martin P. Basic principles of nuclear medicine techniques for detection and evaluation of trauma and sports medicine injuries. *Semin Nucl Med.* 1988;18(2):90–112.
21. Constantini N, Finestone AS, Hod N, et al. Equipment modification is associated with fewer stress fractures in female Israel border police recruits. *Mil Med.* 2010;175(10):799–804.
22. Lauder TD, Williams MV, Campbell CS, Davis G, Sherman R, Pulos E. The female athlete triad: prevalence in military women. *Mil Med.* 1999;164(9):630–5.
23. Babatunde OO, Forsyth JJ. Association between depot medroxyprogesterone acetate (DMPA), physical activity and bone health. *J Bone Miner Metab.* 2013. doi:10.1007/s00774-013-0497-y.
24. Wasserzug O, Balicer RD, Boxman J, Klement E, Ambar R, Zimhony O. A cluster of septic olecranon bursitis in association with infantry training. *Mil Med.* 2011;176(1):122–4.
25. Army HDOT, MC C. *FM 21-10 MCRP 4-11.1D.* 2000.
26. Wolf JM, Mountcastle S, Burks R, Sturdivant RX, Owens BD. Epidemiology of lateral and medial epicondylitis in a military population. *Mil Med.* 2010;175(5):336–9.
27. Smidt N, van der Windt DAWM, Assendelft WJJ, Deville WLJM, Korthals-de Bos IBC, Bouter LM. Corticosteroid injections, physiotherapy, or a wait-and-see policy for lateral epicondylitis: a randomised controlled trial. *Lancet.* 2002;359(9307):657–62. doi:10.1016/S0140-6736(02)07811-X.

28. Shiri R, Viikari-Juntura E, Varonen H, Heliovaara M. Prevalence and determinants of lateral and medial epicondylitis: a population study. *Am J Epidemiol*. 2006;164(11):1065–74. doi:10.1093/aje/kwj325.
29. Stannard JP, Bucknell AL. Rupture of the triceps tendon associated with steroid injections. *Am J Sports Med*. 1993;21(3):482–5.
30. Van Tassel DC, Owens BD, Wolf JM. Incidence estimates and demographics of scaphoid fracture in the U.S. population. *J Hand Surg Am*. 2010;35(8):1242–5. doi:10.1016/j.jhsa.2010.05.017.
31. Wolf JM, Dawson L, Mountcastle SB, Owens BD. The incidence of scaphoid fracture in a military population. *Injury*. 2009;40(12):1316–9. doi:10.1016/j.injury.2009.03.045.
32. Burtis MT, Faillace J, Martin LF, Hermenau S. Scaphoid fracture detection in a military population: a standardized approach for medical referral. *Mil Med*. 2006;171(5):404–8.
33. Bond CD, Shin AY, McBride MT, Dao KD. Percutaneous screw fixation or cast immobilization for nondisplaced scaphoid fractures. *J Bone Joint Surg Am*. 2001;83-A(4):483–8.
34. Wolf JM, Sturdivant RX, Owens BD. Incidence of de Quervain's tenosynovitis in a young, active population. *J Hand Surg Am*. 2009;34(1):112–5. doi:10.1016/j.jhsa.2008.08.020.
35. Garland FC, Garland CF, Doyle EJJ, et al. Carpal tunnel syndrome and occupation in U.S. Navy enlisted personnel. *Arch Environ Health*. 1996;51(5):395–407. doi:10.1080/00039896.1996.9934428.
36. Bongers FJM, Schellevis FG, van den Bosch WJHM, van der Zee J. Carpal tunnel syndrome in general practice (1987 and 2001): incidence and the role of occupational and non-occupational factors. *Br J Gen Pract*. 2007;57(534):36–9.
37. de Krom MC, Knipschild PG, Kester AD, Thijs CT, Boekkooi PF, Spaans F. Carpal tunnel syndrome: prevalence in the general population. *J Clin Epidemiol*. 1992;45(4):373–6.
38. Mondelli M, Giannini F, Giacchi M. Carpal tunnel syndrome incidence in a general population. *Neurology*. 2002;58(2):289–94.
39. Nordstrom DL, DeStefano F, Vierkant RA, Layde PM. Incidence of diagnosed carpal tunnel syndrome in a general population. *Epidemiology*. 1998;9(3):342–5.
40. Stevens JC, Sun S, Beard CM, O'Fallon WM, Kurland LT. Carpal tunnel syndrome in Rochester, Minnesota, 1961 to 1980. *Neurology*. 1988;38(1):134–8.
41. Wolf JM, Mountcastle S, Owens BD. Incidence of carpal tunnel syndrome in the US military population. *Hand (N Y)*. 2009;4(3):289–93. doi:10.1007/s11552-009-9166-y.
42. Palmer BN. Carpal tunnel syndrome, active component, U.S. Armed Forces, 2000–2010. *MSMR*. 2011;18(7):12–5.
43. Lalumandier JA, McPhee SD, Riddle S, Shulman JD, Daigle WW. Carpal tunnel syndrome: effect on Army dental personnel. *Mil Med*. 2000;165(5):372–8.
44. Shaffer SW, Moore R, Foo S, Henry N, Moore JH, Greathouse DG. Clinical and electrodiagnostic abnormalities of the median nerve in US Army dental assistants at the onset of training. *US Army Med Dep J*. 2012:72–81.
45. Greathouse DG, Root TM, Carrillo CR, et al. Clinical and electrodiagnostic abnormalities of the median nerve in Army dental assistants before and after training as preventive dental specialists. *US Army Med Dep J*. 2011:70–81.
46. Penn-Barwell JG, Bennett PM, Powers D, Standley D. Isolated hand injuries on operational deployment: an examination of epidemiology and treatment strategy. *Mil Med*. 2011;176(12):1404–7.
47. Anakwe REB, Standley DM. Hand injuries at a British Military Hospital on operations. *J Hand Surg Br*. 2006;31(2):240–3. doi:10.1016/j.jhsb.2005.06.025.
48. Miller MA, Hall BT, Agyapong F, Kelly KJ, McArthur T. Traumatic noncombat-related hand injuries in U.S. troops in the combat zone. *Mil Med*. 2011;176(6):652–5.
49. Greer MA. Incidence of metacarpal fractures in U.S. soldiers stationed in South Korea. *J Hand Ther*. 2008;21(2):137–41, (quiz 142). doi:10.1197/j.jht.2007.08.017.
50. Anakwe RE, Aitken SA, Cowie JG, Middleton SD, Court-Brown CM. The epidemiology of fractures of the hand and the influence of social deprivation. *J Hand Surg Br*. 2011;36(1):62–5. doi:10.1177/1753193410381823.

51. Busche MN, Knobloch K, Rosenthal H, Vogt PM. Stress fracture of the hamate body and fourth metacarpal base following military style push-ups: an unusual trauma mechanism. *Knee Surg Sports Traumatol Arthrosc.* 2008;16(12):1158–60. doi:10.1007/s00167-008-0634-7.
52. Taylor KF, Lanzi JT, Cage JM, Drake ML. Radial collateral ligament injuries of the thumb metacarpophalangeal joint: epidemiology in a military population. *J Hand Surg Am.* 2013;38(3):532–6. doi:10.1016/j.jhsa.2012.12.003.
53. Gondusky JS, Reiter MP. Protecting military convoys in Iraq: an examination of battle injuries sustained by a mechanized battalion during Operation Iraqi Freedom II. *Mil Med.* 2005;170(6):546–9.
54. Covey DC. Combat orthopaedics: a view from the trenches. *J Am Acad Orthop Surg.* 2006;14(10 Spec No.):S10–7.
55. Marshall TJJ. Combat casualty care: the Alpha Surgical Company experience during Operation Iraqi Freedom. *Mil Med.* 2005;170(6):469–72.
56. Hofmeister EP, Mazurek M, Ingari J. Injuries sustained to the upper extremity due to modern warfare and the evolution of care. *J Hand Surg Am.* 2007;32(8):1141–7. doi:10.1016/j.jhsa.2007.07.007.
57. Weil YA, Mosheiff R, Liebergall M. Blast and penetrating fragment injuries to the extremities. *J Am Acad Orthop Surg.* 2006;14(10 Spec No.):S136–9.
58. Owens BD, Kragh JFJ, Macaitis J, Svoboda SJ, Wenke JC. Characterization of extremity wounds in Operation Iraqi Freedom and Operation Enduring Freedom. *J Orthop Trauma.* 2007;21(4):254–7.
59. Dougherty AL, Mohrle CR, Galarnau MR, Woodruff SI, Dye JL, Quinn KH. Battlefield extremity injuries in Operation Iraqi Freedom. *Injury.* 2009;40(7):772–7. doi:10.1016/j.injury.2009.02.014.
60. Cancio LC, Horvath EE, Barillo DJ, et al. Burn support for Operation Iraqi Freedom and related operations, 2003 to 2004. *J Burn Care Rehabil.* 2005;26(2):151–61.
61. Chapman TT, Richard RL, Hedman TL, Renz EM, Wolf SE, Holcomb JB. Combat casualty hand burns: evaluating impairment and disability during recovery. *J Hand Ther.* 2008;21(2):150–8, (quiz 159). doi:10.1197/j.jht.2007.12.003.
62. Hedman TL, Renz EM, Richard RL, et al. Incidence and severity of combat hand burns after All Army Activity message. *J Trauma.* 2008;64(2 Suppl):S169–72–(discussion S172–3).
63. Birch R, Misra P, Stewart MPM, et al. Nerve injuries sustained during warfare: part I–Epidemiology. *J Bone Joint Surg Br.* 2012;94(4):523–8. doi:10.1302/0301-620X.94B4.28483.
64. Bowyer G. Debridement of extremity war wounds. *J Am Acad Orthop Surg.* 2006;14(10 Spec No.):S52–6.
65. Beitler AL, Wortmann GW, Hofmann LJ, Goff MJ. Operation Enduring Freedom: the 48th Combat Support Hospital in Afghanistan. *Mil Med.* 2006;171(3):189–93.
66. Eardley WGP, Stewart MPM. Early management of ballistic hand trauma. *J Am Acad Orthop Surg.* 2010;18(2):118–26.
67. Covey DC, Lurate RB, Hatton CT. Field hospital treatment of blast wounds of the musculoskeletal system during the Yugoslav civil war. *J Orthop Trauma.* 2000;14(4):278–86. (discussion 277).
68. Covey DC. Blast and fragment injuries of the musculoskeletal system. *J Bone Joint Surg Am.* 2002;84-A(7):1221–34.
69. Lin DL, Kirk KL, Murphy KP, McHale KA, Doukas WC. Evaluation of orthopaedic injuries in Operation Enduring Freedom. *J Orthop Trauma.* 2004;18(8 Suppl):S48–S53.
70. Braakenburg A, Obdeijn MC, Feitz R, van Rooij IALM, van Griethuysen AJ, Klinkenbijl JHG. The clinical efficacy and cost effectiveness of the vacuum-assisted closure technique in the management of acute and chronic wounds: a randomized controlled trial. *Plast Reconstr Surg.* 2006;118(2):390–7. (discussion 398–400).
71. Mendonca DA. Negative pressure wound therapy: an important adjunct to wound care. *South Med J.* 2006;99(6):562–3.

72. Leininger BE, Rasmussen TE, Smith DL, Jenkins DH, Coppola C. Experience with wound VAC and delayed primary closure of contaminated soft tissue injuries in Iraq. *J Trauma*. 2006;61(5):1207–11.
73. Argenta LC, Morykwas MJ. Vacuum-assisted closure: a new method for wound control and treatment: clinical experience. *Ann Plast Surg*. 1997;38(6):563–76. (discussion 577).
74. Morykwas MJ, Argenta LC, Shelton-Brown EI, McGuirt W. Vacuum-assisted closure: a new method for wound control and treatment: animal studies and basic foundation. *Ann Plast Surg*. 1997;38(6):553–62.
75. Fang R, Dorlac WC, Flaherty SF, et al. Feasibility of negative pressure wound therapy during intercontinental aeromedical evacuation of combat casualties. *J Trauma*. 2010;69(1 Suppl):S140–5.
76. Taylor CJ, Chester DL, Jeffery SL. Functional splinting of upper limb injuries with gauze-based topical negative pressure wound therapy. *J Hand Surg Am*. 2011;36(11):1848–51. doi:10.1016/j.jhsa.2011.08.023.
77. Gustilo RB, Anderson JT. Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. *J Bone Joint Surg Am*. 1976;58(4):453–8.
78. Wilton KW, Dickens JF, Heckert R, et al. Heterotopic ossification resection after open peri-articular combat-related elbow fractures. *J Surg Orthop Adv*. 2013;22(1):30–5.
79. Stein DA, Patel R, Egol KA, Kaplan FT, Tejwani NC, Koval KJ. Prevention of heterotopic ossification at the elbow following trauma using radiation therapy. *Bull Hosp Jt Dis*. 2003;61(3–4):151–4.
80. Alfieri KA, Forsberg JA, Potter BK. Blast injuries and heterotopic ossification. *Bone Joint Res*. 2012;1(8):192–7.
81. Kumar AR, Grewal NS, Chung TL, Bradley JP. Lessons from the modern battlefield: successful upper extremity injury reconstruction in the subacute period. *J Trauma*. 2009;67(4):752–7. doi:10.1097/TA.0b013e3181808115.
82. Fleming ME, Watson JT, Gaines RJ, O'Toole RV. Evolution of orthopaedic reconstructive care. *J Am Acad Orthop Surg*. 2012;20(1 Suppl):S74–9. doi:10.5435/JAAOS-20-08-S74.
83. Grewal NS, Kumar AR, Onsgard CK, Taylor BJ. Simultaneous revascularization and coverage of a complex volar hand blast injury: case report using a contralateral radial forearm flow-through flap. *Mil Med*. 2008;173(8):801–4.
84. Chattar-Cora D, Perez-Nieves R, McKinlay A, Kunasz M, Delaney R, Lyons R. Operation Iraqi freedom: a report on a series of soldiers treated with free tissue transfer by a plastic surgery service. *Ann Plast Surg*. 2007;58(2):200–6.
85. Tintle SM, Wilson K, McKay PL, Andersen RC, Kumar AR. Simultaneous pedicled flaps for coverage of complex blast injuries to the forearm and hand (with supplemental external fixation to the iliac crest for immobilization). *J Hand Surg Br*. 2010;35(1):9–15. doi:10.1177/1753193409347428.
86. Potter BK, Burns TC, Lacap AP, Granville RR, Gajewski D. Heterotopic ossification in the residual limbs of traumatic and combat-related amputees. *J Am Acad Orthop Surg*. 2006;14(10 Spec No.):S191–7.
87. Alfieri KA, Forsberg JA, Potter BK. Blast injuries and heterotopic ossification. *Bone Joint Res*. 2012;1(8):192–7.
88. Moritomo H, Tada K, Yoshida T. Early, wide excision of heterotopic ossification in the medial elbow. *J Shoulder Elbow Surg*. 2001;10(2):164–8. doi:10.1067/mse.2001.112055.
89. Baldwin K, Hosalkar HS, Donegan DJ, Rendon N, Ramsey M, Keenan MAE. Surgical resection of heterotopic bone about the elbow: an institutional experience with traumatic and neurologic etiologies. *J Hand Surg Am*. 2011;36(5):798–803. doi:10.1016/j.jhsa.2011.01.015.
90. Department of the Army H. Army Regulation 40–501. 2011.

Chapter 9

Hip Injuries

Joseph T. Lanzi and Steven J. Svoboda

Introduction

Hip injuries are becoming an increasing problem in the population in general, and they have had a significant impact on the military with its young, soldier athletes. The physical and tactical training requirements of military personnel cause tremendous amounts of both force and torque to travel through the hip joint. These forces generated during military training are analogous to those experienced by high-level athletes during intense training and competition. The ground reaction forces transferred through the body from these activities have been linked to musculoskeletal injuries [1]. During normal walking and running, the hip experiences loads 6–8 times the body weight [2]. Recent advances in the understanding of injuries around the hip and their treatment have created the potential for individuals to return to an active lifestyle. The importance of hip pain evaluation and treatment has gained growing importance in the active, athletic population.

Several studies have been performed looking at the impact of various types of injuries it has on various populations [3–6]. The impact of these injuries results in significant strain on the patient and economy. The military population is required to perform duties and activities that place greater strain on the hip joint than the average population. These injuries, along with others, result in loss of man-hours, depletion of manpower for deployment, and increased health-care costs [7–10].

There are several conditions that cause hip pain, some of which are only now becoming better understood. Hip pain can be classified into intra-articular, extra-articular, or mimickers. Historically, many injuries would be treated with

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145

prolonged activity restriction and therapy; however, recent advancements in imaging and understanding of anatomy have enabled physicians to better diagnose and select new and emerging treatment options for these complex patients.

Anatomy

The bony anatomy of the hip joint is comprised of the acetabulum and the femoral head. They articulate as a true ball and socket joint allowing motion in multiple planes. A capsulolabral complex that includes the labrum, capsule, and ligaments provides stability and support during normal motion [11, 12]. While the bony anatomy and capsulolabral complex set the permitted motion of the hip joint, the surrounding musculature is responsible for providing the motion.

Knowledge of the muscular anatomy surrounding the hip is essential to understanding, diagnosing, and treating hip injuries. The iliopsoas and rectus femoris muscles act as the primary hip flexors with secondary flexors including the pectineus, sartorius, and tensor fascia lata muscles [13]. The gluteus maximus and hamstrings are responsible for hip extension. The three adductors (adductor longus, adductor brevis, and adductor magnus) with gracilis facilitate hip adduction, while the gluteus medius and minimus are responsible for abduction. Only the gluteus minimus and the tensor fascia lata in a minor way stimulate internal hip rotation. The muscles assisting external rotation include the gluteus maximus and multiple small external rotators (superior and inferior gemellus, obturator internus and externus, piriformis, and quadratus).

Intra-articular Hip Disorders

Labral Tears

Tears of the labrum are one of the most common causes for subspecialty referral for hip pain. Degenerative tears of the labrum were first identified in dysplastic and arthritic hips as a result of abnormally increased loads about the labrum [14]. Labral tears have now been associated with multiple pathologic states that result in increased strain on the acetabular labrum, including trauma and femoroacetabular impingement [15–17]. As our understanding of hip injuries has evolved, we have recognized that activities that require repetitive pivoting, or twisting, and hip flexion result in an increased incidence of labral tears [18].

Patients will typically present with a gradual onset of pain in the anterior aspect of the hip or groin that may be related to a particular event. This pain is typically exacerbated by activity, especially sports, and prolonged sitting. Some patients describe mechanical symptoms associated with particular movements and may walk

with a subtle Trendelenburg gait [15]. The most predictive physical exam finding is a positive impingement test, placing the hip in flexion, adduction, and internal rotation [15].

Diagnosis of labral tears is difficult, and patients often go extended periods of time before achieving a correct diagnosis [15, 19]. In asymptomatic active duty service members, labral tears can be found in over 80% of the individuals with magnetic resonance imaging [20]. With such a large number of labral tears present in subjects without symptoms of hip pain, it seems reasonable to conclude that the prevalence of hip labral tears would only increase with the appearance of symptoms. However, studies have demonstrated that 22% of the athletes with groin pain and just over half of individuals with mechanical symptoms have labral tears on advanced imaging or arthroscopy [21–23]. Clinically, it is difficult to determine whether a labral tear is the cause of hip dysfunction or if it is present simply as a distracter to the true underlying pathology.

Femoroacetabular Impingement

Femoroacetabular impingement (FAI) typically presents as pain located in the groin. This pain routinely increases with prolonged sitting and activity, especially those activities involving repetitive hip flexion and cutting movements [24]. Most patients describe a gradual onset of pain and increasing limitations. FAI is the result of an anatomic variation of the acetabulum, femoral head-neck junction, or both that causes abnormal contact forces [25, 26]. In a young, active, military population, the prevalence of radiographic evidence of FAI in those who present with complaints of hip pain is over 85% [27].

Patients with hip impingement have reproduction of pain when the hip is brought into flexion, adduction, and internal rotation. They typically have internal rotation of less than 20° and when placed into a figure-of-four position, the affected side will have an increase in the distance from the table to the lateral side of the knee compared to the asymptomatic contralateral side.

FAI is not just a primary cause for injury to the hip in active duty service members. The presence of this anatomic variation may be associated with other problems for the hip as it is subjected to the rigors of military service. Studies evaluating active duty patients with femoral neck stress fractures have found that greater than 50% of the individuals had at least one radiographic finding consistent with FAI [28, 29]. It may also cause athletic pubalgia and sports hernias in high-performance athletes as a result of the abnormal motion in the hemi-pelvis with incidence ranging from 15 to 40% [30, 31]. As this information was collected from nonmilitary, high-performance athletes, the translation of this to the military population may represent an under- or overestimate. More research is needed regarding this topic to determine the prevalence of these types of injuries in a military population.

Osteoarthritis

Hip arthritis is the result of progressive joint degeneration that results in significant pain and dysfunction. It has been reported that arthritis affects over 27 million Americans with a direct yearly cost ranging from \$2650 to 5700 per person [32, 33]. The majority of these costs are productivity-based secondary to work time lost. The prevalence of hip osteoarthritis (OA) in the general population ranges from 2.7 to 25% [34, 35]. OA of the hip results in associated comorbidities and a higher mortality rate when compared to non-arthritic individuals [36, 37].

A patient with an arthritic hip will complain of the gradual, usually atraumatic onset of pain. The hip is painful and stiff in the morning with improvement in symptoms after beginning activity. This pain worsens again in the afternoon and with periods of prolonged standing or activity. Typical radiographic findings include joint space narrowing, subchondral sclerosis and cysts, and osteophyte formation. Despite the uniformly good results of total joint arthroplasty for hip arthritis, it results in significant lifestyle and activity limitations for the relatively young military members treated in this way.

The incidence of hip arthritis in the military may be lower than in the civilian population, estimated at 35/100,000 person-years compared to 56–88/100,000 person-years, respectively [7]. Branch of service (particularly Army, Navy, and Marines), sex (female), age (>40), and race (black) were associated with increased adjusted incidence rate ratios for the development of arthritis [7]. While the overall incidence of hip OA in the military is lower than the general population, this is likely secondary to the large percentage of young individuals that make up the military. An incidence of 140 per 100,000 person-years in service members over 40 years old is much larger than the incidence in general population [7].

Stress Fractures

Stress fractures are another common cause of hip pain in active duty service members. These injuries can occur in the femoral neck, acetabulum, or pubic rami. Stress-related injuries are not unique to a military population but do occur at a higher rate given the requirements of rigorous training particularly among initial entry trainees. Stress fractures of all anatomic regions have been reported to occur in up to 30% of the trainees, with pelvic or acetabular stress fractures representing the smallest fraction between 1–10% of all stress injuries [38–40]. Stress fractures result from a sudden increase in loads placed on healthy or compromised bone. The repetitive stress causes a normal response of bone remodeling with resorption and new bone formation. There is an imbalance in the normal remodeling process that occurs resulting in the reparative process being overwhelmed. Nutrition, endocrine, and other mechanical factors can significantly affect this process.

Secondary to the nature of military service and entry training, these other factors play a significant role in increasing the prevalence of this injury. The prevalence

of femoral neck stress fractures in military trainees has been reported at 12 in 10,000 recruits [41]. It has been noted that 40% of the individuals who sustain femoral neck stress fractures during military training were medically discharged from service [41].

Extra-articular Disorders

Greater Trochanteric Pain Syndrome

Greater trochanteric pain syndrome (GTPS) accounts for 10–20% of the hip pain patients presenting to primary care physicians [42, 43]. A cadaveric study has demonstrated six bursae surrounding the greater trochanter associated with the gluteal tendons [44]. The gluteal tendons have been compared to the rotator cuff of the hip [45]. While there is no proven etiology for GTPS, overuse and injury to these muscles and tendons have been postulated to bring about this pathologic state.

In active duty service members, there is a reported overall incidence of 2.03 cases/1000 person-years with a significant difference between men and women, 1.33 versus 6.16/1000 person-years [9]. Comparing the branches of service, individuals serving in the Army were more likely to have GTPS at a rate of 3.15/1000 person-years, the next service was the air force at 1.67 [9]. Similar to studies performed on a civilian population, the incidence of GTPS in the military was highest among older service members with an incidence of 3.23 in those 40 or older compared to 2.94/1000 person-years in service members less than 20 years old [9]. This study also demonstrated a racial difference in service members with white service members being at higher risk than blacks [9].

While this study does provide us with information on risk factors for GTPS, it does not address the man-hours lost to training and deployment, medical costs to include physical therapy, or productivity. This information is vital to improving our ability to prevent and develop improved treatment plans for this and other disorders.

Miscellaneous Hip Disorders

There are other sources of hip pain that affect active individuals including snapping hip syndrome, athletic pubalgia, sports hernia, osteitis pubis, and piriformis syndrome. In active duty service members, these injury patterns are seen with some regularity throughout military treatment facilities. However, the incidence and risk factors for these injuries have yet to be explored. It is important for physicians treating musculoskeletal conditions to be aware of these injuries and understand that they are found in active individuals. However, without more research to help

determine the true incidence and risk factors associated with these injuries, physicians will continue to have difficulty finding ways to help units limit the disability of an injured soldier.

Conclusions

Our understanding of hip disease prevalence within populations and incidence rates in various groups has recently become more mature. The natural history of the conditions is continuing to be uncovered and new procedures developed that seek to treat the injuries of the hip joint. The indications and contraindications for various procedures involving the hip are just beginning to mature. Just as the understanding of the anatomical basis of hip disorders has recently undergone great expansion over the past decade or two, the techniques to treat many of these disorders are just beginning to become mainstream in orthopedic subspecialty practice. As the natural history of many of these disorders is poorly understood, it remains difficult to determine whether the outcomes of these newer procedures will represent an improvement, unless well-controlled randomized controlled trials are ultimately performed. To compound the difficulties in providing the best care for hip disorders, the military population is a unique cohort with inherent challenges and extrapolating the incomplete science of hip disorders in the nonmilitary high-demand patient population to the military population is fraught with risks. This should serve as a strong “call-to-arms” in regard to providing resources to fund research that better defines the prevalence and incidence of all hip-related injuries in the military population and to guide diagnosis and treatment guidelines that are evidence-based specifically for military members. In particular, greater understanding of the long-term outcomes of the treatment of FAI in the military population should be a priority due to its high prevalence, its natural history that predictably leads to OA, and compelling early outcomes in civilian populations suggesting improved return to activity at short and medium term follow-up. Should this also be the case in the military population, there is potential to mitigate the disability that occurs from this disease and keep service members performing at a high level for longer periods. Given the relatively slow development of arthritis in the hip joint, study of the military population in regard to arthritis related to FAI could inform treatments for other populations with this disease.

References

1. Hewett TE, Myer GD, Ford KR, Heidt RS Jr, Colosimo MV, Succop P. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am J Sports Med.* 2005;33(4):492–501.
2. Gabriel SE, Crowson CS, Campion ME, O’Fallon WM. Direct medical costs unique to people with arthritis. *J Rheumatol.* 1997;24:719–25.

3. Felson DT, Zhang Y. An update on the epidemiology of knee and hip osteoarthritis with a view to prevention [review]. *Arthritis Rheum.* 1998;41:1343–55.
4. Segal NA, Felson DT, Torner JC, et al. Greater trochanteric pain syndrome: epidemiology and associated factors. *Arch Phys Med Rehabil.* 2007;88(8):988–92.
5. Almeida SA, Williams KM, Shaffer RA, Brodine SK. Epidemiological patterns of musculoskeletal injuries and physical training. *Med Sci Sports Exerc.* 1999;31(8):1176–82.
6. Owens BD, Mountcastle SB, Dunn WR, DeBaradino TM, Taylor DC. Incidence of anterior cruciate ligament injury among active duty US military servicemen and servicewomen. *Mil Med.* 2007;172:90–1.
7. Scher DL, Belmont PJ, Mountcastle S, Owens BD. The incidence of primary hip osteoarthritis in active duty US military servicemembers. *Arthritis Rheum.* 2009;61:468–75.
8. Rauh MJ, Macera CA, Trone DW, Shaffer RA, Brodine SK. Epidemiology of stress fracture and lower-extremity overuse injury in female recruits. *Med Sci Sports Exerc.* 2006;38(9):1571–7.
9. Blank E, Owens BD, Burks R, Belmont PJ. Incidence of greater trochanteric pain syndrome in active duty US servicemembers. *Orthopedics.* 2012;35(7):e1022–e7.
10. van Mechelen W. Running injuries: a review of the epidemiological literature. *Sports Med.* 1992;14(5):320–35.
11. Hewitt JD, Glisson RR, Guilak F, Vail TP. The mechanical properties of the human hip capsule ligaments. *J Arthroplasty.* 2002;17(1):82–9.
12. Seldes RM, Tan V, Hunt J, Katz M, Winiarsky R, Fitzgerald RH Jr. Anatomy, histologic features, and vascularity of the adult acetabular labrum. *Clin Orthop Relat Res.* 2001;382:232–40.
13. Frank RM, Slabaugh MA, et al. Posterior hip pain in an athletic population: differential diagnosis and treatment options. *Sports Health.* 2010;2(3):237–46.
14. Haene RA, Bradley M, Villar RN. Hip dysplasia and the torn acetabular labrum: an inexact relationship. *J Bone Joint Surg Br.* 2007;89:1289–92.
15. Burnett RSJ, et al. Clinical presentation of patients with tears of the acetabular labrum. *J Bone Joint Surg Am.* 2006;88:1448–57.
16. Kelly BT, et al. Arthroscopic labral repair in the hip: Surgical technique and review of the literature. *Arthroscopy.* 2005;21:1496–504.
17. Tibor LM, Sekiya JK. Differential diagnosis of pain around the hip joint. *Arthroscopy.* 2008;24:1407–21.
18. Guanche CA, Sikka RS. Acetabular labral tears with underlying chondromalacia: a possible association with high-level running. *Arthroscopy.* 2005;21:580–5.
19. Hunt D, Clohisey J, Prather H. Acetabular tears of the hip in women. *Phys Med Rehabil Clin N Am.* 2007;18(3):497–520.
20. Schmitz MR, Campbell SE, Fajardo RS, Kadrmas WR. Identification of acetabular labral pathological changes in asymptomatic volunteers using optimized, noncontrast 1.5-T magnetic resonance imaging. *Am J Sports Med.* 2012;40:1337–41.
21. Narvani AA, Tsiridis E, et al. A preliminary report on the prevalence of acetabular labrum tears in sports patients with groin pain. *Knee Surg Sports Traumatol Arthrosc.* 2003;11:403–8.
22. McCarthy JC, Noble PC, et al. The Otto E Aufranc award: the role of labral lesions to development of early degenerative hip disease. *Clin Orthop.* 2001;393:25–7.
23. Groh MM, Herrera J. A comprehensive review of hip labral tears. *Curr Rev Musculoskelet Med.* 2009;2(2):105–17.
24. Philippon MJ, Schenker ML. Arthroscopy for the treatment of femoroacetabular impingement in the athlete. *Clin Sports Med.* 2006;25:299–308.
25. Hack K, Di Primio G, Rakhra, K., et al. Prevalence of cam type femoroacetabular impingement morphology in asymptomatic volunteers. *J Bone Joint Surg Am.* 2010;92(14):2436–44.
26. Ganz R, Parvizi J, Beck M, et al. Femoroacetabular impingement: a cause for osteoarthritis of the hip. *Clin Orthop Relat Res.* 2003;417:112–20.
27. Ochoa LM, Dawson L, Patzkowski JC, et al. Radiographic prevalence of femoroacetabular impingement in a young population with hip complaints is high. *Clin Orthop Relat Res.* 2010;468(10):2710–4.

28. Kuhn KM, Riccio AI, Saldua NS, et al. Acetabular retroversion in military recruits with femoral neck stress fractures. *Clin Orthop Relat Res.* 2010;468(3):846–51.
29. Carey T, Key C, Oliver D, Biega T, Bojescul J. Prevalence of radiographic findings consistent with femoroacetabular impingement in military personnel with femoral neck stress fractures. *J Surg Orthop Advances.* 2013;22(1):54–8.
30. Hammoud S, Bedi A, et al. High incidence of athletic pubalgia symptoms in professional athletes with symptomatic femoroacetabular impingement. *Arthroscopy.* 2012;28(10):1388–95.
31. Meyers WC, McKechnie A, Philippon MJ, Horner MA, Zoga AC, Devon ON. Experience with “sports hernia” spanning two decades. *Ann Surg.* 2008;248:656–65.
32. Gabriel SE, Crowson CS, Campion ME, O’Fallon WM. Direct medical costs unique to people with arthritis. *J Rheumatol.* 1997;24:719–25.
33. Maetzel A, Li LC, Pencharz J, Tomlinson G, Bombardier C, the Community Hypertension and Arthritis Project Study Team. The economic burden associated with osteoarthritis, rheumatoid arthritis, and hypertension: a comparative study. *Ann Rheum Dis.* 2004;63:395–401.
34. Lawrence RC, Hochberg MC, Kelsey JL, McDuffie FC, Medsger TA, Felts WR, et al. Estimates of the prevalence of selected arthritic and musculoskeletal diseases in the United States. *J Rheumatol.* 1989;16:427–41.
35. Jordan JM, Linder GF, Renner JB, Fryer JG. The impact of arthritis in rural populations. *Arthritis Care Res.* 1995;8:242–50.
36. Monson RR, Hall AP. Mortality among arthritics. *J Chronic Dis.* 1976;29:459–67.
37. Heliovaara M, Makela M, Impivaara O, Knekt P, Aromaa A, Sievers K. Association of overweight, trauma and workload with coxarthrosis: a health survey of 7,217 persons. *Acta Orthop Scand.* 1993;64:513–8.
38. Kelly EW, et al. Stress fractures of the pelvis in female Navy recruits: an analysis of possible mechanisms of injury. *Mil Med.* 2000;165:142–6.
39. Anderson M, Greenspan A. Stress fractures. *Radiology.* 1996;199:1–12.
40. Williams TR, Puckett ML, et al. Acetabular stress fractures in military endurance athletes and recruits: incidence and MRI and scintigraphic findings. *Skeletal Radiol.* 2002;31:277–81.
41. Talbot JC, Cox G, Townend M, Langham M, Parker PJ. Femoral neck stress fractures in military personnel, a case series. *J R Army Med Corps.* 2008;154(1):47–50.
42. Roberts WN, Williams RB. Hip pain. *Prim Care.* 1988;15(4):783–93.
43. Lievense A, Bierma-Zeinstra S, Schouten B, Bohnen A, Verhaar J, Koes B. Prognosis of trochanteric pain in primary care. *Br J Gen Pract.* 2005;55(512):199–204.
44. Woodley SJ, Mercer SR, Nicholson HD. Morphology of the bursae associated with the greater trochanter of the femur. *J Bone Joint Surg Am.* 2008;90(2):284–94.
45. Kagan A II. Rotator cuff tears of the hip. *Clin Orthop Relat Res.* 1999;368:135–40.

Chapter 10

Knee Injuries

Jeremy McCallum and John M. Tokish

Overview

The US active duty military is a unique population. It is one of the few professions that require physical fitness standards as an occupational necessity. Failure to maintain these standards can have career-ending effects on the individual and on the population level, and can have a significant impact on the nation's ability to defend itself. In 2010, there were some four divisions (40,000 soldiers) in the US Army alone who were classified as “medically not ready” and therefore unavailable to deploy in support of the Global War on Terror (GWOT) [1]. Musculoskeletal injury is the leading cause of disability in this population [2]. Cross et al. reported in 2010 that extremity injuries account for over two thirds of all inpatient hospital costs and disability payments and noticed that posttraumatic osteoarthritis is the single greatest cause of disability in the Department of Defense (DOD) [3]. This finding highlights the severe impact of the “Disease/Non-Battle Injury” (DNBI) on the readiness of the American active duty. Often thought of as “in garrison” or “non-combat” injuries, they are often overlooked as a source of disability in the combat soldier. But considering that these injuries account for roughly 1 million lost duty days per year [1], they have a far larger impact on battlefield readiness than their more traditional combat injury counterparts. This holds true even in the combat arena. Belmont et al. followed a brigade combat team during the “surge” in Fallujah for injuries that removed soldiers from the battlefield. The authors found that over 50 % of these injuries were due to musculoskeletal DNBI [4].

The most common joint affected by the DNBI injury is the knee, and knee conditions represent the most frequent cause of surgical intervention in the US active duty [5].

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153

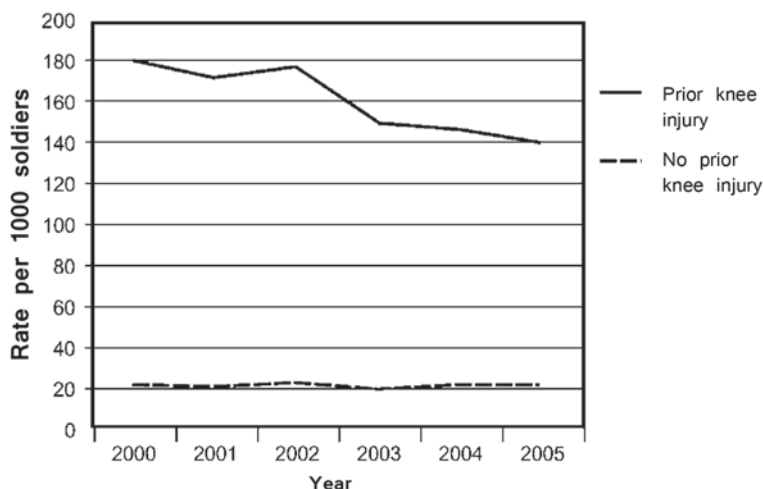


Fig. 10.1 Rates of knee injury in active duty Army, 2000–2005: stratified by prior knee injury status (Rate per 1000 soldiers may fall in more than one category per year) [6]

The incidence of acute knee injuries to include sprains, strains, and dislocations in the active duty sector is 21–25 per 1000 soldiers [6]. This is elevated compared to both collegiate athletes and the general population. In National Collegiate Athletic Association (NCAA) soccer and basketball athletes, there is a reported incidence of 1.4–3.8 injuries in games and practice per 1000 athletes exposed [7–10]. In general population studies, acute care visits for knee injuries are estimated to be between 2.29 and 6 per 1000 person-years [11, 12].

Certain risk factors are associated with increased incidence of knee injury in soldiers (Fig. 10.1).

These include age, rank, military occupation (MOS), gender, and those with category IV Armed Forces Qualification Test Score (AFQTS) [6]. In addition, a history of prior knee injury within 2 years increases the risk of subsequent knee injury tenfold [6]. Soldiers allowed into the military with a medical waiver for a knee injury were 8.0 times more likely to be hospitalized for a knee condition and 14.0 times more likely to be medically discharged for a knee-related condition [13].

Over a recent 5-year period, 148,951 orthopedic surgical procedures were performed on 132,731 active duty soldiers to treat musculoskeletal DNBI, including over 60,000 knee procedures [5]. Unfortunately, not all of these surgeries resulted in return to duty. We analyzed the reoperation rates for many common orthopedic procedures and found the knee to be among the highest to receive revision operation of the same type, with an overall rate of 9%. Meniscectomy cases (medial or lateral) underwent a revision surgery of the same type 14% of the time, and chondroplasty and anterior cruciate ligament (ACL) had repeated ratios of 12 and 10%, respectively [5]. The reoccurrence of injury is a matter of concern and is likely due to a number of causes including the physically demanding lifestyle, and the pressure for an accelerated return to one's unit. Decreased mortality in the field seen in recent

years has also led to increased demand on the armed forces rehabilitation assets, perhaps contributing to less emphasis placed on DNBI-related injuries [14].

Increased age has been shown to be related to increased risk of knee injury [6]. Soldiers less than 20 years of age have an incidence of 15–19 per 1000, whereas those of 20–30 years display an incidence of 20–25 per 1000 [6]. Active duty members who are greater than 30 years have an incidence of 24–28 per 1000 [6]. This increased incidence with age may be related to accumulation of prior knee injuries or the increasing pressure for a quick return for those in leadership positions. Related to age, length of service is also associated with an increase in the rate of knee injuries, with soldiers serving less than 1 year having the lowest rates of knee injury, and those serving greater than 10 years having the highest rates [6]. Rank is also a factor with enlisted troops demonstrating knee injuries at a rate of 22–26 per 1000, whereas officers are slightly lower at 20–23 per 1000 [6]. There are many potential explanations for these differences. Enlisted troops include those going through basic training, who have shown to have higher rates of acute traumatic musculoskeletal injuries [15], and officers may be underrepresented in certain more physical duty designations.

No difference has been reported with regard to ethnicity or education. However, there is a difference among soldiers taking the AFQTS [6]. The AFQTS is inversely proportional to the rate of knee injury. Those scoring in group I (the highest group) have the lowest rate of knee injury, 18–24 per 1000 person-years [6]. Those scoring in group IV (the lowest group) have an injury rate of 24–30 per 1000 person-years and were 20–62 % higher than group I every year [6].

Acute Meniscal Injury

Meniscal injuries and their treatment are common in both the general and military population. The meniscus' primary function is to distribute compressive forces during dynamic joint movements and static loading [16]. Injuries occur secondary to sports as well as during everyday living. Symptoms such as pain, catching, and locking often need to be treated with surgery. Arthroscopic treatment of meniscal tears is very common, with many centers reporting a rate of 10–20 % of all surgical procedures and totalling approximately 1 million surgeries in the USA annually [17, 18]. In the military, arthroscopic treatment of meniscal tears is the most common knee procedure performed with more than 5700 cases annually [5], with nearly 90 % being debridement.

The incidence of acute meniscal injury is higher in the military compared to the general population and has several associated risk factors such as gender, age, rank, branch of service, and ethnicity. The mean incidence of meniscal tears in the general population is 0.33–0.61 per 1000 person-years [19, 20]. The military population has a greater than tenfold increase over the general population, with an incidence of 8.27 per 1000 person-years [21]. These findings are consistent with increased incidence also seen in other knee pathology.

Injury to the meniscus in the general population is more common in males than females with a 2.5–4:1 ratio [22]. Similarly, military men were 20% more likely than their female counterparts to have an acute meniscal injury [21].

One military study reports that increased age and a higher incidence of meniscal injury are associated; however, this is not consistent with prior data in civilian populations that show peak incidence in men 21–30 years old [21, 23]. In the military, soldiers greater than 40 years old are four times more likely to have a meniscal tear when compared to soldiers less than 20. The difference in age of occurrence between the general population and active duty may be attributed to civilian personnel becoming more sedentary as they age, whereas active duty has daily duty requirements that require continued athletic activity leading to meniscal injuries.

Stratification in incidence of meniscal injury is seen through the ranks. Junior enlisted claim the highest incidence of meniscal injuries followed by senior enlisted and senior officers. Junior officers have the lowest rate of injury [21]. Junior enlisted may be at increased risk because those soldiers are undergoing basic training, which has been shown to have inherent increased risk of musculoskeletal and knee injuries [15].

In addition to age and gender, branch of service can affect the incidence of injury. Active duty members in the Army or Marine Corps have higher rates of acute meniscal injuries than the Navy and Air Force [21].

Analysis of race in the active duty population demonstrates association between ethnicity and injury. Three ethnic categories are defined as whites, blacks, and others. Whites and blacks have similar rates of meniscal injury, which is 25% lower than other classified ethnicities [21].

In published civilian data, the medial meniscus is injured two to four times more frequently than the lateral meniscus [19, 24–26]. Jones et al. reported similar findings in the active duty population breaking the injuries into three groups: 50.3% of the injuries occur to the medial meniscus, 22.4% to the lateral, and 27.3% are not specified [21]. Anatomical analysis explains these differences. The lateral meniscus is more mobile than the medial meniscus that is attached firmly to the joint capsule, leading to higher incidence of injury in the medial meniscus [18, 27].

The menisci play an important role in knee joint stabilization, lubrication, and proprioception [28–30]. Injuries have been associated with long-term changes to include joint dysfunction, degenerative changes, and osteoarthritis [31, 32]. Significant increase in incidence of meniscus injury in soldiers is a unique problem for this population, as osteoarthritis is the single most common cause of disability in the US DOD.

Treatment of meniscal tears is particularly challenging for the military surgeon. It is not uncommon for the soldier to be delayed in having access to an orthopedic surgeon, and thus it is a common perception that many patients are managed conservatively with these injuries for an inordinate amount of time. Such management combined with the aggressive physical requirements of a military member as well as the cultural pressure to keep up with daily physical training often results in severe and irreparable meniscal damage at the time of surgery. Meniscal repair makes up around only 10% of meniscal type surgery, reflecting the severity of the encountered

pathology. Further, the cultural pressure of a quick return to duty makes prolonged rehabilitation, such as that required of a meniscal repair, quite challenging.

Cartilage

Chondral injuries can occur as an isolated entity or in combination with other knee pathology. Approximately 3650 chondroplasties are performed every year in the military, which accounts for the second most common knee surgery in this population [5]. Injury to the cartilage has been reported in 9% of soldiers with acute ACL injuries and the incidence increases with a delay in surgical treatment [33]. Treatment options for chondral injury range from minimally invasive arthroscopic debridements, to more in-depth chondral transplants. Each approach has its proponents with trade-offs in cost, durability, and time to recovery. Very little literature is available to contrast the different forms of treatment within a military population, but some data do compare these techniques in young athletic populations which may be extrapolated to active duty service members. Gudas et al. performed a randomized clinical trial comparing microfracture to an osteochondral autograft transfer system (OATS) procedure in young athletes and noticed that while OATS patients returned to their previous level of sports at a rate of 93%, microfracture patients only returned to this level 52% of the time [34]. A follow-up study by the same authors at 10 years showed that the OATS group maintained their activity in 75% of patients compared to just 37% in the microfracture group [35]. There are challenges in translating civilian data to the military experience, however. The treatment of larger chondral lesions with an allograft OATS, for example, has not yielded analogous results. Two studies have evaluated the allograft OATS as it relates to return to activity [26, 36] in civilian populations. Both studies reported high rates of patient satisfaction and nearly 80% return to sport. In contrast, Shaha et al. studied the same procedure in a military population and found that only 29% returned to full duty. Further, only 5% of patients in that study claimed to return to their previous level of sport [37].

The disparity in these results may be partially explained by certain military-specific factors that make chondral injuries more difficult to treat in active duty. The Marine Corps, for example, does not allow for any modification of activity on a long-term basis, and therefore, any Marine who undergoes chondral treatment must return to full duty without limitation or is medically discharged. In addition, the Marine Corps gives a limited duty or “LimDu” for a single 6-month period, and may grant a second in rare circumstances. If the Marine has not returned to duty by the end of the LimDu, he or she is boarded out of the Corps. Another possibility lies in the definition of “return to activity.” In most civilian populations, patients can achieve return and still self-limit activity, whereas a military population generally has daily physical mandatory formations that do not accommodate self-limitation. Thus, with the limited time available for recovery, and the rigorous daily physical requirements required upon return, chondral pathology is a very sobering diagnosis in a military population.

Ligament Injuries

Anterior Cruciate Ligament (ACL)

Injury to the ACL is a common injury in any young active population. Given the soldier's daily physical demands, it is not surprising that reported rates of ACL injuries in the military are ten times that of the civilian population [16]. The overall incidence of ACL injuries in US active duty servicemen and women is 2.96–3.65 per 1000 [16]. These rates are significantly higher than what is seen in the civilian population that has rates between 0.31 and 0.38 per 1000 (107,108). Over 3000 ACL reconstructive surgeries are performed annually in the military medical system and are the third most common knee procedure performed [5].

There have been multiple studies investigating the rate of ACL injury in men compared to women in a military population. Examining a select population at the US Naval Academy, Gwinn was able to demonstrate increased risk of ACL injuries in female midshipmen [38]. This cohort may not represent the entire US military; however, as Owens et al. evaluated the larger military population, controlling for age and race, no difference was found in the incidence of ACL tears between men and woman active duty members [16].

Return to duty status after ACL reconstruction is reported in level III studies. Return to duty for all military personnel has been reported in as high as 92% of patients [39]. This data should be interpreted carefully, however, as many patients who undergo ACL reconstruction remain on physical limitations for a protracted period of time. Recent data demonstrate that three fourths of military patients who underwent an isolated ACL reconstruction are still on duty limitations ("profile") at 3 months out from surgery, and one fourth remain there at 9 months out from surgery [1].

Revision surgery resulted in longer recoveries and longer time on a limited duty status compared to those patients undergoing a primary repair [39].

ACL injuries can occur as an isolated injury or as a combination of injuries to the structures about the knee. Individuals with ACL injuries will often have concurrent injuries of the cartilage and menisci. In the active duty population, 33.3% of soldiers who have an acute ACL tear also sustain a medial meniscus injury, while 40% suffer a lateral meniscus injury [33]. Patients who have subacute or chronic ACL injuries without restrictions of their activities have an increase and change in incidence of a meniscal injury. In the subacute group, 44% suffer injury to the medial meniscus, while 51.7% have an injured lateral meniscus [33]. Those with chronic ACL injuries have the highest rates of meniscal injury, with the medial meniscus injured in 79.5% and the lateral meniscus injured in 61.5% of patients [33]. Anatomically, the medial meniscus acts as a secondary joint stabilizer and therefore is placed at a higher risk for injury in patients whose primary stabilizer, the ACL, has been injured for a long period of time. The relative risk of injury to the medial and lateral menisci in soldiers with chronic ACL injuries is 7.75 and 2.4, respectively [33]. Data from the military population are similar to that of the general population where the prevalence of a meniscal injury with an acute ACL tear

is estimated to be between 41 and 82% and with a chronic injury 58–100% [33]. Increase in age is not associated with increase in risk for concurrent meniscal injury with an ACL tear [33]. Incomplete tears are more common in the lateral meniscus compared to the medial meniscus [33]. Meniscal tears associated with ACL ruptures are generally complete, longitudinal, and localized to the posterior meniscus close to the meniscocapsular junction [33].

Chondral lesions are also commonly associated with ACL injury. In the general population, chondral lesions are found to increase from 19% at the time of ACL injury to as high as 70% in patients having chronic injuries. In the active duty population, chondral injuries are found in about 9% of patients with acute ACL injuries [33]. This number increases to 26% in those with subacute injuries and as high as 70% in patients with a chronic ACL tear. Active duty soldiers who have chronic untreated ACL injuries are 23 times more likely to have a chondral injury than soldiers with acute injuries [33]. In the active duty population, 55% of patients with an ACL injury have a least two associated lesions to the cartilage or menisci, and 79% of soldiers in the chronic ACL insufficient group have two lesions, almost 15 times higher than the acute group (20%) [33]. Consistent with the above data, 24% of patients more than 30 years old have both meniscus and cartilage lesions, which is significantly higher than the soldiers less than 30 years of age [33].

Treatment of chondral lesions in the setting of ACL deficiency has been recently evaluated. In patients undergoing ACL reconstruction with an associated chondral lesion, Gudas et al. compared debridement, microfracture, and an OATS procedure in a randomized clinical trial. At 3-year follow-up, the authors found that all forms of chondral treatment were inferior to isolated ACL reconstructions, but the OATS group significantly outperformed the microfracture and debridement groups in subjective patient satisfaction, whereas microfracture and debridement were not statistically different [40]. These data suggest that every effort should be made to restore native anatomy as close as possible for optimal return to athletic activities.

Multiligamentous Knee Injury and Knee Dislocation

Multiligamentous knee injuries and knee dislocations can be caused by high-energy trauma, sports injuries, or even a low-energy fall. While the true incidence within the military population is unknown, it is not an uncommon injury, and several reports exist describing the pathology and prognosis associated with these devastating injuries.

Owens et al. performed one such study and noted that 100% of the patients with a knee dislocation had disruption of the ACL and posterior cruciate ligament (PCL), with an additional 86% demonstrating disruption of the posterior lateral corner and 93% sustaining an injury to the lateral collateral ligament [41]. In addition, there was a 3.5% rate of vascular injury, and the peroneal nerve was injured 75% of the time. While 67% of patients with neurologic injury experienced a full recovery, the prognosis of nerve recovery was related to the severity of the injury, as complete nerve injuries generally did not recover meaningful function [41].

Return to duty after treatment of a multiligamentous knee injury in a military population is challenging. Ross et al. reported a return to duty of 54%, with 46% of soldiers eventually undergoing medical discharge for their injury [42]. In that study, there was no correlation between the soldier's MOS (job title) and medical discharge. On the other hand, there was a positive correlation between higher rank and greater percentage return to military duty after surgery [42]. In general, soldiers reported their knees to feel stable, but reported that after surgery and rehab they were able to perform sports at "half speed" and had some limitations in daily living functional scores [42]. Those with associated injuries outside the knee had higher rates of medical discharge, with 67% of soldiers undergoing a medical discharge [42].

The most common reported complication with treatment of the multiligamentous knee injury is arthrofibrosis. Owens et al. noted that 18% of active duty soldiers sustaining a knee dislocation required a second operation for arthrofibrosis, while another 13% had significant stiffness without requirement for a second procedure. The average arc of motion after reconstruction was 119°, with a 1.9° loss of extension and 10.2° loss of flexion [41]. Severe injury to multiple ligaments of the knee to include knee dislocation is a difficult injury to treat with a high rate of associated injury and complications.

Patellofemoral Joint

Dislocations

Acute traumatic patellar dislocation accounts for approximately 3% of all injuries to the knee [43–45] and is caused by a valgus force in flexion in up to 93% of cases [46]. In the civilian population, patellar dislocation has been reported between 0.029 and 0.070 per 1000 person-years, with 61% of these dislocations secondary to an athletic injury [47–49]. Participation in a sport and/or physical activity is associated with patellar dislocation [46, 47, 50]. The rate of patellar dislocation among military personnel is significantly higher than the civilian population, with a rate of 0.69 per 1000 person-years [51]. This finding is echoed in military populations outside the USA [46]. The incidence of patellar dislocation varies by age, gender, military service, rank, and race [51] (Table 10.1).

Patellar dislocation results in injury to the medial patellofemoral ligament, medial retinaculum, and a hemarthrosis in almost all patients [46]. Nearly 25% will have an osteochondral fracture [45], but the clinical significance of this is not well studied. The rate of dislocation is inversely proportional to age, with a higher number occurring in younger age groups. Active duty members less than 20 years are 84% more likely to sustain a dislocation than those who are greater than 40 years old. Similar trends have been demonstrated in civilian populations [47, 50].

Active duty females are 61% more likely to sustain a patellar dislocation when compared to men with an incidence rate of 0.63 per 1000 person-years compared to active duty men with an incidence rate of 0.39 per 1000 person-years [51]. Civilian

Table 10.1 Comparison of previous population-based studies calculating incidence rates for patellar dislocation injuries [51]

Study (duration)	Population	Injuries	Population (person-years)	Age (years)	Incidence rate (per 1000 person-years)
Atkin et al. [52] (3 y) ^a	Civilian, urban	74	1,102,005	11–56	0.067
Fithian et al. [20] (2–5 y) ^a	Civilian, urban	125	1,944,000	10–3 +	0.058
Sillanpaa et al. [15] (5 y)	Military, Finnish	73	96,200	17–30	0.774
Current (10 years)	Military, USA	9299	13,443,448	17–40 +	0.692

^a Results for short- and long-term follow-up within the same cohort

literature demonstrates no difference between men and women in acute primary dislocation rate [49].

Other military-specific factors demonstrate increased risk of patellar dislocation. Higher rates of dislocation are seen in the Marine Corps, Army, and Air Force compared to the Navy, as a marine is 50 % more likely to sustain a dislocation compared to a sailor [51]. Junior officers and enlisted sustain the highest rate of dislocation when comparing ranks, whereas senior officers sustain the least. Senior enlisted suffer more dislocations than junior officers, which suggests rank does play a greater role than just age itself [51].

Recovery and return to duty after a dislocation is slow and significant. Over the first 6 months following injury, up to 50 % of patients report a decline in sports activity and pain associated with cutting, jumping, kneeling, and squatting [47]. Twenty one percent of patients experience functional limitations that prevent them from returning to active duty military service [46]. Recurrent instability and dislocations can be disabling. Some studies report recurrent instability and dislocations in 50 % of patients managed nonoperatively [53, 54]. Patients with two or more dislocations are 6.5 times more likely to experience another episode of instability [50]. Posttraumatic osteoarthritis is common regardless of recurrent instability [55].

Surgical treatment of patellar dislocation is likely more common in a military population than in civilians because of the soldier's inability to avoid exacerbating activities that is a mainstay of conservative treatment.

Patellofemoral Pain Syndrome

Retropatellar pain during activity or patellar femoral pain syndrome (PFPS) exists commonly throughout the military ranks. One study evaluating male infantry recruits found that 15 % of recruits had patellofemoral pain related to overactivity in a 6-week period [56]. Two risk factors were identified. The first was that a larger medial tibial intercondylar distance (which is influenced by both the axis of the knee and mediolateral bowing of the tibia) led to higher incidence of the diagnosis [56]. Second, a stronger quadriceps muscle was associated with more symptoms [56]. A

subsequent study performed at the US Naval Academy defines PFPS as retropatellar pain during at least two of the following activities: (1) ascending/descending stairs (2) hopping/jogging, and (3) prolonged sitting, kneeling, and squatting with negative findings of examination of the knee's ligaments, menisci, bursa, and synovial plica and with pain on palpation of either of the patellar facets or femoral condyles [57]. The incidence in this population is 22 per 1000 person-years, and the prevalence is 13.5 %, with females being 2.3 times more likely than males to be diagnosed with PFPS [57]. The elevated rate of injury in females has been attributed to females having increased Q angles, dynamic frontal plane alignment, and lower extremity muscle strength [57]. While PFPS is a major source of disability and loss to readiness in the active duty soldier, perhaps no diagnosis is more difficult to study. PFPS tends to be a "catch-all" term with diagnoses such as excessive lateral compression syndrome, patellar chondromalacia, patellar tendinosis, and quadriceps dysfunction often interchangeably used. The mainstay for treatment in this population is conservative rehabilitation, though failure rates with this form of treatment are likely underreported.

Osteoarthritis

Osteoarthritis is the most common cause of disability in adults in the USA, affecting an estimated 26.9 million adults [58] and accounting for approximately 2600–7500 in out-of-pocket expense per year and affecting close to 27 million people [48, 58, 59]. Occupational physical demands and traumatic joint injury have been associated with the development of osteoarthritis. The military population is no different, where osteoarthritis is the most common disability among US service members who have been medically separated from active duty [2].

Injuries to the knee have been shown to have up to 100 % reported osteoarthritis compared to other joints [60]. Nearly 95 % of osteoarthritis in service members can be attributed to injuries sustained while on active duty, and in combat-related osteoarthritis, fractures and traumatic arthrotomies secondary to explosive devices account for 75 % of these patients' injuries. On average, the interval between these injuries to the knee and a formal diagnosis of osteoarthritis is approximately 19 months [60].

The treatment for end-stage osteoarthritis often requires total knee arthroplasty (TKA). This procedure has been reported in military populations with good results at 2–3 years after arthroplasty [61, 62]. The average age of the wounded warrior undergoing arthroplasty is significantly younger than that of the general population of arthroplasty patients [62]. No long-term data are available for TKA done in a military-specific population, but return to duty is possible with a permanent profile in services that allow it. Unfortunately, however, because of young age and higher activity load in this population, TKA remains a limited option for this condition as it may cause increased wear, osteolysis, and limitations of duty. Thus, it is often reserved for members at the completion of their career or after retirement.

Table 10.2 Prevalence of osteoarthritis in comparison to the general population [63]

OA type	Traumatic amputees		General population ^a	
	Male (%)	Female (%)	Male (%)	Female (%)
Knee	28.3	22.2	1.58	1.33
Hip	15.3	11.1	1.13	0.98

^a Year prevalence of osteoarthritis in general practitioner registration standardized for age and sex in the Netherlands in 2000 [16]

One aspect of osteoarthritis that is highlighted in a military population concerns the traumatic amputation, where these patients have demonstrated an increased prevalence (27%) of knee osteoarthritis (OA) in their normal limb compared with the general population (Table 10.2) [64].

Alterations in gait and increased joint loads exhibited by amputees are a hypothesized cause of pain and degeneration [62, 63], and with the increased numbers of traumatic blast and amputations sustained as a result of the GWOT, it is likely that posttraumatic joint replacement will become a much more common procedure as time progresses.

Activity-Specific Injuries

Parachuting

There is perhaps no more “signature” high-risk activity for the soldier than the parachute jump. Many variations on the theme exist, including the so-called high-altitude low opening (HALO) jump in which the jumper egresses the aircraft between 15,000 and 30,000 feet, and free falls at terminal velocity until opening his or her parachute at the lowest altitude possible to allow a safe landing. Injuries can occur during deployment, descent, and landing. During deployment, static line injuries can occur to the upper extremity. These type of injuries were reduced by development of a new technique in 1994 [65]. If the soldier’s legs are above him during the free fall, his legs can become entangled in the rigging and lead to injury to the knee—specifically the collateral ligaments [66]. Impact injuries with the ground causes the majority of injuries [65–68] of which 80% involved the lower extremity [68].

The incidence of injuries during parachuting in the military is reported to range between 3 and 24 injuries per 1000 jumps [69–75]. The wide range is secondary to different types of jumps (static line versus free fall), terrain, and experience. Hallell and Naggan reported variation of injuries based on difficulty of jumps. The incidence for easy jumps was 2.2 injuries per 1000 compared to 25.7 for most difficult jump conditions [71]. In one study, only 18% of these injuries involved the knee, most being minor and only 5% involving disruption of the knee ligaments [68]. Of all the injuries reported, only 14% were severe (fracture or ligamentous disruption).

Another study demonstrated that of the severe injuries that were sustained during parachuting, 30% involved the disruption of the knee ligaments and 1.4% involved fractures of either the patella or tibial plateau [76].

Multiple variables can change the risk of injury during a jump. The incidence of injury generally decreases after a soldier has received his or her initial basic training and gradually matches the rate of more expert jumpers [68]. Increasing difficulty of conditions to include uneven terrain and light conditions (night jumps) increase the number of injuries [77]. Injury rate also increases with age as does the number of severe versus minor injuries [67, 68]. Other factors including higher wind speed, jumps from airplanes opposed to helicopters or balloons, jumps with equipment, and female gender also raise the risk of injury.

Combatives

The US military has taught combative courses at its military academy for many years; however, the MAC or Modern Army Combatives program was only initiated in 1995 [78]. Since that time, it has spread throughout the Army and in 1997 became a required training by every unit [78]. While the exact incidence of knee injury is unknown, it is the most commonly injured body part in combatives, which lead to limitation of duties (Fig. 10.2).

According to a study by Possley et al., knee injuries account for 24.5% of all injuries reported [78], and surgical intervention was required for 9% of injuries to the knee [78]. Meniscal debridement was the most common knee procedure performed followed by microfracture [78].

Basic Training

Basic training is a unique experience in which soldiers are immersed in military customs, learn basic skills, and participate in unit physical training. During training, illness, overuse, and traumatic injuries lead to an average 0.64 clinic visits per recruit, with total injury rates ranging from 18 to 35 per 100 recruits [79]. Women experience more time loss due to injuries than do men, with women having 32 days per 100 person weeks of limited duty for musculoskeletal injuries compared to 10 days per 100 person weeks for men [52]. Risk factors for injury included gender (female), low levels of running performance (men and women), and increased body-mass index (BMI) with an inactive lifestyle (men) [52]. Overuse knee injuries during basic training accounts for 2.1–16% of these reported injuries [52, 79], while traumatic knee injuries accounted for about 19% of the injuries [79]. Kaufman et al. published a review of injuries comparing basic training to other types of specialized military training, which demonstrates that the knee was the predominate site of injury in almost all levels of training (Table 10.3) [80]

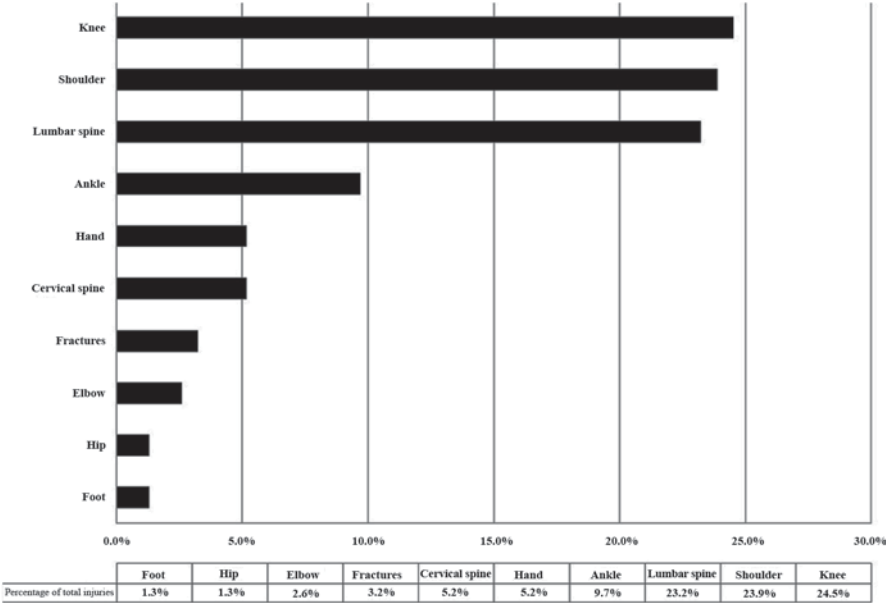


Fig. 10.2 Frequency of injury per body part in combatives [78]

Table 10.3 Regional distribution of lower extremity injuries reported in military personnel [33]

				Site (% of injuries)				
Study	Year	Population	Observa- tion period (weeks)	Foot	Ankle	Lower leg	Knee	Lower back
Riddell [81]	1990	Royal marines commando training center, N= 18,040; all male	52 (1981)	14.7	16.7	3.8	26.7	—
			52 (1985)	11.9	14.2	5.5	18.8	—
Linenger et al. [77]	1993	Naval special warfare, N=88	25	9.8	15.0	11.2	34.3	6.3
Jones et al. [27]	1993	Army infan- tery, N= 303; all male	12	10.9	10.9	8.6	10.2	5.9
Knapik et al. [50]	1993		26	6.6	12.3	2.4	10.4	6.6
Almeida et al. [37]	1999		12	34.9	12.9	3.1	21.7	4.1
Brodine and Shaffer ^a	1995		25	9.8	14.0	11.2	34.3	6.3
Shaffer et al. [58]	1999		9	24.0	22.0	18.7	21.7	9.9
			13	5.4	14.3	21.4	33.8	8.6
			10	13.7	23.5	20.3	24.8	7.5

^a SB, RS. Unpublished data, 1999

Conclusions

Knee injuries are a very common cause of duty limitation and long-term disability in the US active duty. The occupational requirements, the inability of the individual soldier to be able to self-limit, and the protracted time available for recovery and rehabilitation all contribute to the complexity of treating these injuries in this population. With the operational tempo that has become the norm since the beginning of the GWOT, the rate and complexity of these injuries will continue to increase, and there is an increasing need for more definitive treatments for the active duty soldier and veteran.

References

1. JM T. Military contributions that advance AANA's mission. Paper presented at Arthroscopy association of North America. 2013; San Antonio, Texas.
2. Cross JD, Ficke JR, Hsu JR, Masini BD, Wenke JC. Battlefield orthopaedic injuries cause the majority of long-term disabilities. *J Am Acad Orthop Surg*. 2011;19 Suppl 1:1–7.
3. Cross JD. Sources of long-term disability in the US military. Paper presented at: extremity war injuries. 2010; Washington, DC.
4. Belmont PJ Jr, Goodman GP, Waterman B, DeZee K, Burks R, Owens BD. Disease and nonbattle injuries sustained by a US Army Brigade Combat Team during Operation Iraqi Freedom. *Mil Med*. 2010;175(7):469–76.
5. JM T. The repeat ratio of surgeries to treat common musculoskeletal disease/non battle injuries within the active duty military population, 2005–2010. Paper presented at: society of military orthopaedic surgeons. 2009; San Diego, CA.
6. Hill OT, Kay AB, Wahi MM, McKinnon CJ, Bulathsinhala L, Haley TF. Rates of knee injury in the US Active Duty Army, 2000–2005. *Mil Med*. 2012;177(7):840–4.
7. Agel J, Evans TA, Dick R, Putukian M, Marshall SW. Descriptive epidemiology of collegiate men's soccer injuries: national collegiate athletic association injury surveillance system, 1988–1989 through 2002–2003. *J Athl Train*. 2007;42(2):270–7.
8. Agel J, Olson DE, Dick R, Arendt EA, Marshall SW, Sikka RS. Descriptive epidemiology of collegiate women's basketball injuries: national collegiate athletic association injury surveillance system, 1988–1989 through 2003–2004. *J Athl Train*. 2007;42(2):202–10.
9. Dick R, Hertel J, Agel J, Grossman J, Marshall SW. Descriptive epidemiology of collegiate men's basketball injuries: national collegiate athletic association injury surveillance system, 1988–1989 through 2003–2004. *J Athl Train*. 2007;42(2):194–201.
10. Dick R, Putukian M, Agel J, Evans TA, Marshall SW. Descriptive epidemiology of collegiate women's soccer injuries: national collegiate athletic association injury surveillance system, 1988–1989 through 2002–2003. *J Athl Train*. 2007;42(2):278–85.
11. Ferry T, Bergstrom U, Hedstrom EM, Lorentzon R, Zeisig E. Epidemiology of acute knee injuries seen at the emergency department at Umea University Hospital, Sweden, during 15 years. *Knee Surg Sports Traumatol Arthrosc*. 2014;22(5):1149–55. doi:10.1007/s00167-013-2555-3.
12. Gage BE, McIlvain NM, Collins CL, Fields SK, Comstock RD. Epidemiology of 6.6 million knee injuries presenting to United States emergency departments from 1999 through 2008. *Acad Emerg Med*. 2012;19(4):378–85.
13. Cox KA, Clark KL, Li Y, Powers TE, Krauss MR. Prior knee injury and risk of future hospitalization and discharge from military service. *Am J Prev Med*. 2000;18 Suppl 3:112–7.

14. Clark ME, Bair MJ, Buckenmaier CC 3rd, Girona RJ, Walker RL. Pain and combat injuries in soldiers returning from Operations Enduring Freedom and Iraqi Freedom: implications for research and practice. *J Rehabil Res Dev.* 2007;44(2):179–94.
15. Knapik JJ, Craig SC, Hauret KG, Jones BH. Risk factors for injuries during military parachuting. *Aviat Space Environ Med.* 2003;74(7):768–74.
16. Owens BD, Mountcastle SB, Dunn WR, DeBerardino TM, Taylor DC. Incidence of anterior cruciate ligament injury among active duty US military servicemen and servicewomen. *Mil Med.* 2007;172(1):90–1.
17. Cook JL. The current status of treatment for large meniscal defects. *Clin Orthop Relat Res.* 2005;(435):88–95.
18. Renstrom P, Johnson RJ. Anatomy and biomechanics of the menisci. *Clin Sports Med.* 1990;9(3):523–38.
19. Baker BE, Peckham AC, Puppato F, Sanborn JC. Review of meniscal injury and associated sports. *Am J Sports Med.* 1985;13(1):1–4.
20. Lauder TD, Baker SP, Smith GS, Lincoln AE. Sports and physical training injury hospitalizations in the Army. *Am J Prev Med.* 2000;18 Suppl 3:118–28.
21. Jones JC, Burks R, Owens BD, Sturdivant RX, Svoboda SJ, Cameron KL. Incidence and risk factors associated with meniscal injuries among active-duty US military service members. *J Athl Train.* 2012;47(1):67–73.
22. Greis PE, Bardana DD, Holmstrom MC, Burks RT. Meniscal injury: I. Basic science and evaluation. *J Am Acad Orthop Surg.* 2002;10(3):168–76.
23. Poehling GG, Ruch DS, Chabon SJ. The landscape of meniscal injuries. *Clin Sports Med.* 1990;9(3):539–49.
24. Campbell SE, Sanders TG, Morrison WB. MR imaging of meniscal cysts: incidence, location, and clinical significance. *AJR Am J Roentgenol.* 2001;177(2):409–13.
25. Majewski M, Susanne H, Klaus S. Epidemiology of athletic knee injuries: a 10-year study. *Knee.* 2006;13(3):184–8.
26. McDermott ID, Amis AA. The consequences of meniscectomy. *J Bone Joint Surg Br.* 2006;88(12):1549–56.
27. Englund M, Roos EM, Roos HP, Lohmander LS. Patient-relevant outcomes fourteen years after meniscectomy: influence of type of meniscal tear and size of resection. *Rheumatology (Oxford).* 2001;40(6):631–9.
28. Assimakopoulos AP, Katonis PG, Agapitos MV, Exarchou EI. The innervation of the human meniscus. *Clin Orthop Relat Res.* 1992;(275):232–36.
29. Levy IM, Torzilli PA, Warren RF. The effect of medial meniscectomy on anterior-posterior motion of the knee. *J Bone Joint Surg Am.* 1982;64(6):883–8.
30. Levy IM, Torzilli PA, Gould JD, Warren RF. The effect of lateral meniscectomy on motion of the knee. *J Bone Joint Surg Am.* 1989;71(3):401–6.
31. Englund M, Guermazi A, Lohmander SL. The role of the meniscus in knee osteoarthritis: a cause or consequence? *Radiol Clin North Am.* 2009;47(4):703–12.
32. Lohmander LS, Englund PM, Dahl LL, Roos EM. The long-term consequence of anterior cruciate ligament and meniscus injuries: osteoarthritis. *Am J Sports Med.* 2007;35(10):1756–69.
33. Yuksel HY, Erkan S, Uzun M. The evaluation of intraarticular lesions accompanying ACL ruptures in military personnel who elected not to restrict their daily activities: the effect of age and time from injury. *Knee Surg Sports Traumatol Arthrosc.* 2006;14(11):1139–47.
34. Gudas R, Kalesinskas RJ, Kimtys V, et al. A prospective randomized clinical study of mosaic osteochondral autologous transplantation versus microfracture for the treatment of osteochondral defects in the knee joint in young athletes. *Arthroscopy.* 2005;21(9):1066–75.
35. Gudas R, Gudaitė A, Pocius A, et al. Ten-year follow-up of a prospective, randomized clinical study of mosaic osteochondral autologous transplantation versus microfracture for the treatment of osteochondral defects in the knee joint of athletes. *Am J Sports Med.* 2012;40(11):2499–508.
36. Krych AJ, Robertson CM, Williams RJ 3rd, Cartilage Study G. Return to athletic activity after osteochondral allograft transplantation in the knee. *Am J Sports Med.* 2012;40(5):1053–9.

37. Shaha JSCJ, Rowles DJ, Bottoni CR, Shaha SH, Tokish JM. Return to an athletic lifestyle following osteochondral allograft transplantation of the knee. *Am J Sports Med.* 2013;(Accepted, in press).
38. Gwinn DE, Wilckens JH, McDevitt ER, Ross G, Kao TC. The relative incidence of anterior cruciate ligament injury in men and women at the United States Naval Academy. *Am J Sports Med.* 2000;28(1):98–102.
39. Enad JG, Zehms CT. Return to full duty after anterior cruciate ligament reconstruction: is the second time more difficult? *J Spec Oper Med.* 2013;13(1):2–6.
40. Gudas R, Gudaite A, Mickevicius T, et al. Comparison of osteochondral autologous transplantation, microfracture, or debridement techniques in articular cartilage lesions associated with anterior cruciate ligament injury: a prospective study with a 3-year follow-up. *Arthroscopy.* 2013;29(1):89–97.
41. Owens BD, Neault M, Benson E, Busconi BD. Primary repair of knee dislocations: results in 25 patients (28 knees) at a mean follow-up of four years. *J Orthop Trauma.* 2007;21(2):92–6.
42. Ross AE, Taylor KF, Kirk KL, Murphy KP. Functional outcome of multiligamentous knee injuries treated arthroscopically in active duty soldiers. *Mil Med.* 2009;174(10):1113–7.
43. Arendt EA, Fithian DC, Cohen E. Current concepts of lateral patella dislocation. *Clin Sports Med.* 2002;21(3):499–519.
44. Harilainen A, Myllynen P, Antila H, Seitsalo S. The significance of arthroscopy and examination under anaesthesia in the diagnosis of fresh injury haemarthrosis of the knee joint. *Injury.* 1988;19(1):21–4.
45. Stefancin JJ, Parker RD. First-time traumatic patellar dislocation: a systematic review. *Clin Orthop Relat Res.* 2007;455:93–101.
46. Sillanpaa P, Mattila VM, Iivonen T, Visuri T, Pihlajamaki H. Incidence and risk factors of acute traumatic primary patellar dislocation. *Med Sci Sports Exerc.* 2008;40(4):606–11.
47. Atkin DM, Fithian DC, Marangi KS, Stone ML, Dobson BE, Mendelsohn C. Characteristics of patients with primary acute lateral patellar dislocation and their recovery within the first 6 months of injury. *Am J Sports Med.* 2000;28(4):472–9.
48. Gabriel SE, Crowson CS, Campion ME, O'Fallon WM. Direct medical costs unique to people with arthritis. *J Rheumatol.* 1997;24(4):719–25.
49. Waterman BR, Belmont PJ Jr, Owens BD. Patellar dislocation in the United States: role of sex, age, race, and athletic participation. *J Knee Surg.* 2012;25(1):51–7.
50. Fithian DC, Paxton EW, Stone ML, et al. Epidemiology and natural history of acute patellar dislocation. *Am J Sports Med.* 2004;32(5):1114–21.
51. Hsiao M, Owens BD, Burks R, Sturdivant RX, Cameron KL. Incidence of acute traumatic patellar dislocation among active-duty United States military service members. *Am J Sports Med.* 2010;38(10):1997–2004.
52. Jones BH, Bovee MW, Harris JM 3rd, Cowan DN. Intrinsic risk factors for exercise-related injuries among male and female Army trainees. *Am J Sports Med.* 1993;21(5):705–10.
53. Cofield RH, Bryan RS. Acute dislocation of the patella: results of conservative treatment. *J Trauma.* 1977;17(7):526–31.
54. Maenpaa H, Lehto MU. Patellofemoral osteoarthritis after patellar dislocation. *Clin Orthop Relat Res.* 1997(339):156–62.
55. Maenpaa H, Huhtala H, Lehto MU. Recurrence after patellar dislocation. Redislocation in 37/75 patients followed for 6–24 years. *Acta Orthop Scand.* 1997;68(5):424–6.
56. Milgrom C, Finestone A, Eldad A, Shlamkovitch N. Patellofemoral pain caused by over-activity. A prospective study of risk factors in infantry recruits. *J Bone Joint Surg Am.* 1991;73(7):1041–3.
57. Boling M, Padua D, Marshall S, Guskiewicz K, Pyne S, Beutler A. Gender differences in the incidence and prevalence of patellofemoral pain syndrome. *Scand J Med Sci Sports.* 2010;20(5):725–30.
58. Lawrence RC, Felson DT, Helmick CG, et al. Estimates of the prevalence of arthritis and other rheumatic conditions in the United States. Part II. *Arthritis Rheum.* 2008;58(1):26–35.

59. The burden of musculo-skeletal diseases in the United States. Prevalence, Social and Economic Cost. Paper presented at American Academy of Orthopaedic Surgeons. 2008; Rosemont, IL.
60. Rivera JC, Wenke JC, Buckwalter JA, Ficke JR, Johnson AE. Posttraumatic osteoarthritis caused by battlefield injuries: the primary source of disability in warriors. *J Am Acad Orthop Surg.* 2012;20 Suppl 1:64–9.
61. Haspl M, Pecina M, Orlic D, Cicak N. Arthroplasty after war injuries to major joints. *Mil Med.* 1999;164(5):353–7.
62. Kuklo TR, Heekin RD, Temple HT, Islinger RB, Horan PJ. A review of total joint replacement in active duty soldiers. *Mil Med.* 1997;162(3):201–4.
63. Norvell DC, Czerniecki JM, Reiber GE, Maynard C, Pecoraro JA, Weiss NS. The prevalence of knee pain and symptomatic knee osteoarthritis among veteran traumatic amputees and nonamputees. *Arch Phys Med Rehabil.* 2005;86(3):487–93.
64. vHC SPA, Hitters MW, Smeets RJ. The prevalence of osteoarthritis of the intact hip and knee among traumatic leg amputees. *Arch Phys Med Rehabil.* 2009(90):440–6.
65. Bricknell MC, Craig SC. Military parachuting injuries: a literature review. *Occup Med (Lond).* 1999;49(1):17–26.
66. Richman RM, Barnes KO. Acute instability of the ligaments of the knee as a result of injuries to parachutists. *J Bone Joint Surg Am.* 1946;28:473–90.
67. D D. Retrospective study of injuries in military parachuting. *Med J Armed Forces India.* 2007;(63):353–55.
68. Ekeland A. Injuries in military parachuting: a prospective study of 4499 jumps. *Injury.* 1997;28(3):219–22.
69. Essex-Lopresti P. The hazards of parachuting. *Br J Surg.* 1946;34:1–13.
70. Farrow GB. Military static line parachute injuries. *Aust N Z J Surg.* 1992;62(3):209–14.
71. Hallel T, Naggan L. Parachuting injuries: a retrospective study of 83,718 jumps. *J Trauma.* 1975;15(1):14–9.
72. Kiel FW. Hazards of military parachuting. *Mil Med.* 1965;130:512–21.
73. Lillywhite LP. Analysis of extrinsic factor associated with 379 injuries occurring during 34,236 military parachute descents. *J R Army Med Corps.* 1991;137(3):115–21.
74. Petras AF, Hoffman EP. Roentgenographic skeletal injury patterns in parachute jumping. *Am J Sports Med.* 1983;11(5):325–8.
75. Pirson J, Verbiest E. A study of some factors influencing military parachute landing injuries. *Aviat Space Environ Med.* 1985;56(6):564–7.
76. Ciccone R, Richman RM. The mechanism of injury and the distribution of 3000 fractures and dislocations caused by parachute jumping. *J Bone Joint Surg Am.* 1948;30 A(1):77–97.
77. Knapik JJ, Sharp MA, Canham-Chervak M, Hauret K, Patton JF, Jones BH. Risk factors for training-related injuries among men and women in basic combat training. *Med Sci Sports Exerc.* 2001;33(6):946–54.
78. Possley DR, Johnson AE. Musculoskeletal injuries sustained in modern Army combatives. *Mil Med.* 2012;177(1):60–3.
79. Popovich RM, Gardner JW, Potter R, Knapik JJ, Jones BH. Effect of rest from running on overuse injuries in Army basic training. *Am J Prev Med.* 2000;18 Suppl 3:147–55.
80. Kaufman KR, Brodine S, Shaffer R. Military training-related injuries: surveillance, research, and prevention. *Am J Prev Med.* 2000;18 Suppl 3:54–63.
81. McCulloch PC, Kang RW, Sobhy MH, Hayden JK, Cole BJ. Prospective evaluation of prolonged fresh osteochondral allograft transplantation of the femoral condyle: minimum 2-year follow-up. *Am J Sports Med.* 2007;35(3):411–20.

Chapter 11

Lower Leg, Ankle, and Foot Injuries

Brian R. Waterman, John Dunn, and Justin D. Orr

Lower Leg

Tibial Stress Fracture

Introduction

Stress fractures and the broader spectrum of stress-related injuries occur on a continuum in response to overuse activity. With repetitive impact and loading forces, these injuries arise from cumulative microtrauma that results in mechanical compromise with eventual fatigue-related failure. While also occurring in the midfoot, metatarsals, femur, pelvis, and vertebrae, the tibial stress fracture is most common, particularly among active cohorts [1].

When evaluating stress-related conditions of the tibia, two discreet entities should be considered. Medial tibial stress syndrome (MTSS), or “shin splint syndrome,” is a broad-based stress-related injury of unclear etiology involving the posteromedial tibial shaft. Proposed theories identify periosteal traction at sites of muscular attachment and deformation with mechanical bending as potential contributors to its development, although a complex interplay of biomechanical, biological, and morphological factors are likely present. Alternatively, true tibial stress fractures are less common but higher risk. These fractures develop at the anterior tibial cortex in response to continuous tensile loads and may manifest radiographically with a “dreaded black line” and thickened anterior cortex in a chronic situation (Figs. 11.1–11.3).

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171

Fig. 11.1 Tibia stress fracture. (Note: dreaded black line)



Epidemiology

With a reported incidence of 0.5%, tibial stress fractures can be found among a well-defined, broad demographic population [2]. More classically, distance runners and military recruits have sustained higher rates of stress injuries, particularly those involving the tibia [3–5]. However, these injuries are not specific to these cohorts as tibial stress fractures have been described in a variety of sports such as ballet, volleyball, rowing, basketball, and gymnastics [6].

Among military populations, tibial stress injuries typically occur in untrained service members undergoing repetitive, intense physical activity and/or training programs for combat readiness, such as in basic training or advanced specialized military courses. Several studies have demonstrated that 1–31% [4, 7] of military recruits will incur a stress fracture, while up to 53% may experience MTSS [8]. Cosman et al. demonstrated that the cumulative 4-year incidence of single-stress fractures among US Military Academy (USMA) cadets was 5.7% for males and 19.1% for females, with approximately 50% of injuries occurring within the first 3 months of enrollment [9]. Among the broader US Armed Forces, Lee and colleagues [10] determined that the mean annual incidence rate of tibial stress fractures was 3.24 per 1000 person-years between 2004 and 2010. In the largest sample of US Army recruits, the incidence rate of tibial stress fractures was 19.3 and 79.9 cases per 1000 male and female recruits, respectively [5]. In addition to the medi-

Fig. 11.2 Bone scan with focal uptake of tibia stress fracture



cal burden of injury, the financial repercussions of stress fractures is not negligible, with the estimated cost approximately US\$34,000 per US service member [11].

Many factors may contribute to the development of a tibial stress fracture. These are typically separated into intrinsic and extrinsic risk factors. However, more recently, the medical and public health community has been increasingly focused on the identification of modifiable risk factors as a means to improve injury prevention. Intrinsic factors for tibial stress fractures, including female sex, white race,

Fig. 11.3 Tibia stress fracture status post intramedullary nail at 6 months



older age, increased bone turnover, anatomic malalignment, and decreased tissue or bone vascularity have been identified and are largely non-modifiable. General physical fitness, muscle endurance, bone density, steroid or tobacco use, excessive alcohol consumption, and hormonal deficiencies are among the intrinsic factors that may be alternatively considered modifiable variables. Extrinsic factors include training regimen, dietary or nutritional profile, footwear, and training surface, and these factors may also be considered as targets for intervention and risk mitigation [12, 13].

Female sex is among the more notable risk factors associated with stress fractures, particularly within the military, in general, where they are at up to a 2-to 12-fold greater risk of stress injury than males [14–21]. While classically associated with the female athlete triad (i.e., eating disorders, functional hypothalamic amenorrhea, and osteoporosis), stress fractures can arise as a result of a multitude of factors. Known risk factors include underlying differences in bone geometry (e.g., smaller and more narrow tibia) and microarchitecture (e.g., decreased bone mineral density, greater trabecular volume), altered hormonal regulation, nutritional deficiencies, reduced muscle mass, and diminished physical fitness [20]. Given communal training within the military setting, lower levels of physical fitness among women lead to greater comparative physical effort, earlier fatigue, and altered gait or running mechanics, which could further exacerbate the risk of overuse injuries in the lower extremity [14, 22].

Training regimens, primarily dramatic increases in vigorous impact and running activity, contribute significantly to the development of tibial stress injuries. As a result, the study among military cadets and recruits during basic training is ideal and has helped develop the existent body of literature. In contradistinction to athletics where physical activity is more consistent throughout adolescence and adulthood, military enlistment is often preceded by a period of sedentary lifestyle or decreased general fitness, which may heighten secondary risk of stress fracture. Cosman and colleagues [9] demonstrated that cadets at USMA were at a twofold greater risk of stress injury when they had exercised less than 7 h per week in the year prior to matriculation. Furthermore, the rate, duration, and intensity of military training (e.g., marching, running) have been associated with rates of tibial stress fracture [10]. Consequently, redesigned training programs with decreased cumulative exposure, implementation of minimum sleep requirements, and greater emphasis on agility exercises and cross-training have been successful at mitigating the rates of tibial stress fracture without compromising unit readiness [10, 23, 24].

While there have been several attempts at preventative treatment, few measures have led to a decrease in rates of tibial stress injury. Adjusted training schedules and individualized risk stratification have been most successful in injury reduction [10, 25]. There is also limited evidence that suggests a relative risk reduction with the use of shock-absorbing insoles when compared with controls. However, the optimal insole design and shoe wear modifications are undetermined. Calcium and vitamin D supplementation have been widely promoted for the prevention of fragility fractures, and recent evidence certainly supports its use within a military population at risk for tibial stress fractures, particularly when deficiencies or other risk factors exist [26]. Conversely, pre-exercise stretching and medial arch supports for excessive pronation have not been found to demonstrate a protective effect from stress-related fracture [27].

Chronic Exertional Compartment Syndrome

Introduction

Chronic exertional compartment syndrome (CECS), or exercise-induced compartment syndrome, is a common source of lower extremity disability among active patients. First described by Mavor in 1956, CECS has historically referred to involvement of the leg, although cases affecting the shoulder, upper arm, forearm, hand, gluteus, thigh, and foot have also been described [28].

As with other overuse conditions of the lower extremity, the pathophysiology of CECS is only partially understood. During normal exercise, the muscle volume increases by up to 20% or up to 20-fold greater than its resting size, with pressures exceeding 500 mmHg [29]. In response to increased metabolic demands, blood perfusion rises in turn with accumulation of interstitial fluid. However, when this is coupled with chronic fascial thickening, limited tissue compliance [30], diminished capillary density [31], and/or elevated baseline intracompartmental pressures, pa-

tients with CECS are unable to accommodate exercise-related changes and experience symptoms as a result of relative tissue ischemia and nerve compression [32]. In response to these changes, patients complain of pain and neurovascular symptoms, which often precipitate early cessation of athletic activity and military training. Alternatively, acute compartment syndrome represents a surgical emergency where tissue ischemia occurs following a traumatic injury or other underlying systemic process, and this should not be confused with CECS.

Epidemiology

CECS occurs most commonly in avid runners, military recruits, and competitive athletes involved in sports such as basketball, soccer, and football. The prevalence of CECS varies widely, with reported rates ranging from 10 to 60% in selected cohorts [33–35]. In a recent evaluation of US military service members over a 6-year time period, the incidence rate of CECS was approximately 0.5 per 1000 person-years [36]. However, given the systematic underreporting coupled with inconsistent diagnostic criteria and specificity, the comprehensive burden of CECS is unknown within the military setting.

Traditionally, CECS has been described among young, active male athletes and military recruits, and the preponderance of cases occur among this demographic [36, 37]. However, limited research may suggest disparate epidemiological trends among patients with CECS, particularly among nontraditional cohorts recently exposed to the rigorous physical demands of the military. As military enlistments and athletic involvement have both continued to increase among females, there has been greater parity in at-risk exposure between males and females. Recent studies demonstrate increased risk among females including one study in US military service members [31, 36]. By contrast, multiple earlier studies suggest no difference in the incidence among men and women [30, 33, 37]. When evaluating by age, Waterman and colleagues [38] also showed a positive association between increased age and the incidence rate of CECS, with patients over 40 years demonstrating a nearly ninefold greater rate of CECS versus those under 20.

Non-commissioned service members, primarily those of junior rank and Army service, showed the highest rates of CECS. This likely reflects the unique physical demands of the junior enlisted service members, often serving in ground military forces with frequent exposure to organized physical fitness training, dismounted field activity, and prolonged marching with a combat load. Overtraining has been implicated, and junior service members may be less able to moderate these intense occupational demands to accommodate physical limitations arising from CECS [38, 39].

In addition to demographic variables, several modifiable factors may also serve as targets for intervention. Abnormal gait patterns and/or prolonged muscular contraction during aerobic exercise may exacerbate the underlying pathophysiology of CECS, by limiting peripheral vascular perfusion during muscle relaxation and increasing intracompartmental pressures. Additionally, repetitive eccentric exercise may diminish fascial compliance with continued exposure, as occurs with the anterior compartment during running [40]. As a result, newer literature has investi-

gated the role of running technique, specifically a forefoot contact pattern, in reducing intracompartmental pressures and mitigating the symptoms related to CECS [41, 42]. In an evaluation of a 6-week forefoot training program for cadets with CECS at USMA, Diebal and colleagues [43] demonstrated significant reductions in anterior compartment pressures (78.4 ± 32 vs. 32 ± 11.5 mmHg) and vertical ground-reaction forces, while improving running distance, speed, exertional pain, and patient-reported outcome measures at up to a year after intervention. Furthermore, all patients avoided surgery and remained on active duty without physical activity restrictions. Creatine and anabolic steroid use can also lead to increased intramuscular fluid volume and hypertrophy, thus diminishing potential space for normal volume expansion and increasing intracompartmental pressures with exercise activity.

While certain anatomic features mentioned previously have been associated with the development of CECS, the role of fascial defects of the leg remains uncertain. Between 10 and 60% of patients presenting for treatment of CECS also had clinically evident fascial defects [39], compared with less than 5% among asymptomatic individuals [28]. While only 1–2 cm² in size, this fascial defect may serve as a site for adjacent superficial peroneal nerve entrapment when localized to the anterolateral intermuscular septum. With continued exercise, muscle and neurovascular herniation may occur, leading to further, localized inflammation and/or micro-ischemia. Further studies are required to better elucidate the underlying contribution of these fascial defects, as well as the underpinnings of disrupted arteriolar homeostasis thought to be central to the development of CECS [28].

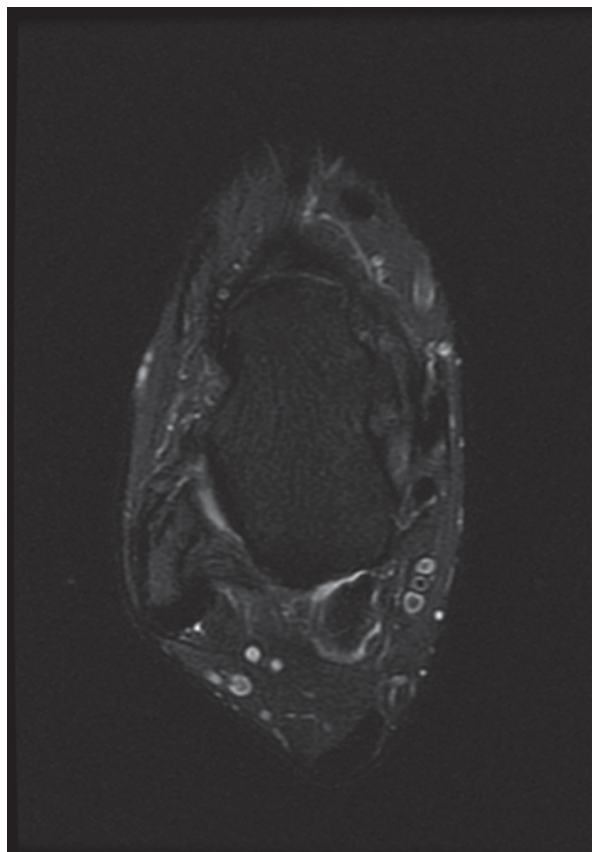
Ankle

Ankle Sprain

Introduction

The so-called ankle sprains can often collectively represent a spectrum of traumatic soft tissue injuries about the ankle and hindfoot, but the diagnosis classically denotes ligamentous instability about the tibiotalar joint with varying degrees of severity [44]. Traditionally, ankle instability comprises three discreet categories of injury, including lateral, medial, and syndesmotic ankle sprain. However, combined ligamentous involvement and other associated injuries, particularly those involving the chondral surface of the talar dome and peroneal tendons, are common. Sprains involving the lateral ligament complex, including the anterior talofibular ligament, calcaneofibular ligament, and posterior talofibular ligament, account for at least 85% of all ankle sprains [45] (Figs. 11.4 and 11.5). Conversely, syndesmotic, or “high ankle sprains,” and medial ankle sprains are diagnosed in only approximately 10–15% of patients with ankle sprains, and the epidemiological literature is fairly limited [46]. The focus of the current review will further elaborate largely on lateral ankle instability.

Fig. 11.4 Axial T2 MRI—
anterior talofibular ligament
(ATFL) disruption



Epidemiology

In active, athletic populations, ankle sprains account for up to 30% of single-sport injuries. Nearly 1.2 million ankle-sprain-related health-care visits occur per year, with an estimated cost of up to US\$3.8 million for both treatment and rehabilitation [47, 48]. The incidence rates of ankle sprain may vary, with between 2 and 7 individuals per 1000 in the general population injured per year [49–51]. However, the risk of ankle sprain is an order of magnitude greater in military cohorts, with reported incidence rates ranging from 35 to 58.4 per 1000 person-years in previous studies [46]. Among military personnel, paratroopers are at a particularly elevated risk. Lillywhite [52] identified that between 0.6 and 1.2% of Royal Army paratroopers sustained ankle injuries per year, with increases up to 7.9% on mass descents. Further studies have shown that ankle sprain accounts for 9–33% of parachute-related injuries and have an incidence rate between 1 and 4.5 per 1000 jumps [53, 54].

To better understand and anticipate the epidemiology of this injury, several authors have sought to identify modifiable risk factors associated with lateral ankle

Fig. 11.5 Coronal T2 MRI—
CFL disruption



sprain [46, 55–57] (Table 11.1). Non-modifiable risk factors can be useful in identifying high-risk populations for injury prevention, while modifiable risk factors such as body mass index (BMI), proprioception or postural stability, and the absence of external restraints to inversion (e.g., prophylactic bracing) can be the targets for intervention [57]. Within the context of this framework, several risk factors for ankle sprain will be discussed.

Non-modifiable Risk Factors

Gender With the increasing popularity and involvement of female athletes in sports, gender-related studies of musculoskeletal injury have become important in determining potential health disparities. The underpinnings of these gender-based discrepancies are likely multifactorial, with several postulated associations including inherent hormonal differences, lower extremity anatomy, limb alignment,

Table 11.1 Risk factors for ankle sprain among athletic populations

Non-modifiable risk factors	Modifiable risk factors
Sex	Weight
Age	Body mass index
Height	Bracing/taping
Race	Footwear
Foot/ankle anatomy	Neuromuscular control
Extremity alignment	Postural stability
Previous ankle sprain	Muscle strength
Generalized joint laxity	Exposure to sport
	Player position
	Playing surface
	Skill level

ligamentous laxity, neuromuscular control, and the extent and type of athletic exposure [57, 58].

Gender studies on ankle sprain incidence, however, have yielded mixed results. A study of military cadets showed incidence rates (IR) of ankle sprain as 96.4 and 52.7 per 1000 person-years for women and men, respectively (incidence rate ratio (IRR) of 1.83 (95 % confidence interval (CI) 1.52–2.20)), while no differences were detected between the male and female intercollegiate athletes [51]. In a separate study of collegiate athletes, Beynnon et al. showed IRs of 1.6 and 2.2 per 1000 person-days for men and women, respectively, although the difference was not statistically significant [59]. Hosea et al. subsequently found that while female athletes had a 25 % greater risk of sustaining a grade I ankle sprain compared with their male counterparts in both high school and intercollegiate basketball, there was no significant difference in the risk for the more severe ankle sprains [60].

Further studies in the general population of the USA show no overall differences by gender, although male individuals between the ages of 15 and 24 and female individuals over the age of 30 had higher rates of ankle sprain than their opposite sex counterparts [51]. A population-based study of active duty military personnel revealed that female service members experienced an incidence rate that was 21 % higher than that of male service members [46]. Based on the available literature, gender appears to be associated with risk of ankle sprain, although additional factors such as exposure to and level of at-risk activity may directly influence this complex relationship.

Age Younger age, particularly when associated with increased exposure to at-risk activity, is also associated with the risk of ankle sprain. Studies of the general population of the USA [46] and Denmark [50] yielded a mean and median patient age of 26.2 and 24.4, respectively. A recent population-based study within an active duty military population reported the highest incidence rates for ankle sprain in the group of those under 20 years old for both male and female subjects, and rates generally declined with increasing age [57]. These studies suggest that peak incidence rates for ankle sprain occur during the second decade of life, with male and female peak incidence rates occurring between the ages of 15 and 19 and 10 and 14, respectively [49, 51].

The mechanism of injury for ankle sprain also varies by age, with a greater preponderance of injuries occurring during recreational or competitive sports in young, active populations [46]. Patients under 25 years of age were more likely to sustain ankle sprains while engaging in athletics and physical activity, while patients over 50 were more likely to incur ankle sprain in their own homes or during activities of daily living [50].

Previous Ankle Sprain Ankle sprain produces damage to ligaments that maintain the stability of the ankle joint, thereby creating potential functional limitations. Some of this damage, such as that resulting in proprioceptive or neuromuscular impairment, is modifiable through exercise. However, the initial inflammatory response following injury can also lead to scar tissue formation, which is more likely than normal tissues to fail due to a 60% reduction in energy-absorbing capacity [61].

Functional instability and increased risk of reinjury may still occur after primary ankle sprain in athletes and military recruits undergoing basic training even if the primary sprain is on the less severe end of the injury spectrum [62–65]. A recent study on track and field athletes and rates of reinjury within 24 months demonstrated that athletes with a grade I or II lateral ankle sprain were at higher risk of reinjury (14 and 29%, respectively) than high-grade acute lateral ankle sprains (5.6%) [65]. However, this may also be related to inadequate rehabilitation of less severe injuries and earlier perceived healing despite persistent proprioceptive impairment, which ultimately increases further risk of recurrence.

Modifiable Risk Factors

Weight and BMI With increasing weight and BMI, an increasing mass moment of inertia acts about the ankle, potentially increasing the risk of ankle sprain. In a study on high school football players, Tyler et al. [66] showed that the incidence of ankle sprain was significantly increased in patients with BMI categorized as above normal or overweight when compared to players with a normal BMI. Waterman et al. [46] reported similar findings in military cadets with ankle sprains who had higher mean weight and BMI than their uninjured counterparts. Interestingly, in the same study, no statistically significant differences in height, weight, or BMI were observed between the injured and uninjured female cadets, but this may have been due to the limited female representation within the studied cohort.

Despite the evidence that weight and BMI are associated with an increased risk of ankle sprain, other studies have failed to demonstrate that these anthropometric measures are independent risk factors for ankle sprain [59, 67]. Certain athletic cohorts or player positions with elevated BMI may be at a greater predisposition for ankle sprain; further research is required to discern these subtle differences.

Neuromuscular Control/Postural Stability Proprioception and broader neuromuscular control were first proposed as a risk factor for ankle sprain by Freeman et al. [68] in 1965. Subsequent studies have extensively and rigorously evaluated proprioceptive deficits after primary ankle sprain and described their resultant effects on strength, postural balance, and ankle stability, particularly in athletic

populations [69–71]. Furthermore, McGuine et al. [72] demonstrated that high school basketball athletes who subsequently sustained ankle sprains had significantly greater measures of pre-injury postural sway when measured with stabi-lometry than their uninjured counterparts, indicating an underlying neuromuscular predisposition. Other studies have reported similar results with clinical assessments of postural stability [73].

However, while gross morphologic changes and disrupted afferent nervous net-works have been noted with ankle sprain and resultant postural instability, its causal link with chronic ankle instability is less clear [74–76]. Muscular fatigue or dimin-ished baseline strength may potentiate neuromuscular impairment and contribute to subsequent ankle instability [77].

Sport Certain athletic activities increase the likelihood of ankle sprain, particularly those that involve frequent running, cutting, and jumping movements. Analysis of the National Electronic Injury Surveillance System (NEISS) for all ankle sprain injuries presenting to emergency departments over a 5-year time period revealed that 49.3% of ankle sprains were caused by participation in sports; basketball (41.1%), football (9.3%), and soccer (7.9%) accounted for more than half of all ankle sprains during athletic activity [51].

A more expansive systematic review of ankle sprain epidemiology revealed that incidence rates varied depending on the unit of measurement [78]. When evaluating for incidence per 1000 person-hours, rugby had the highest incidence (4.20), fol-lowed by soccer (2.52). Conversely, when considering incidence more accurately in terms of athletic exposure, lacrosse had the highest incidence rate (2.56) of sprains per 1000 person-exposures, followed by basketball (1.90). Similarly, Waterman et al. [46] found that basketball (men's, 1.67; women's, 1.14), men's rugby (1.53), and men's lacrosse (1.34) were among the highest incidences per 1000 person-years among intercollegiate athletes.

Level of Competition As a broad category, level of competition has also been identified as a potential risk factor for ankle sprain. Traditionally, level of competi-tion has been synonymously used to describe both intensity of competition (i.e., practice vs. game) and level of skill (e.g., recreational, intercollegiate, and profes-sional). However, both of these components represent distinct variables that should be separately considered and evaluated.

When considering intensity of competition, there is a positive relation between higher level of play and increased risk of ankle sprain, with approximately 55–66% of injuries occurring during games when compared to training sessions [79–82]. This is likely attributable to the increased risk-taking activity and pace of play.

There is less of a consensus on the impact of skill level on the incidence of ankle sprain. Our previous work has revealed that ankle sprain incidence in intercollegiate athletes was seven times that of intramural athletes in terms of injuries per 1000 person-years [46]. However, when more specifically controlling for the extent of athlete exposures, no significant differences between intramural and intercollegiate athletes were noted. Other prior studies evaluating skill level are conflicting; one re-port notes an increased risk in higher-level intercollegiate athletes [60]. Conversely,

two additional studies have revealed an increased risk of sports injuries in lower-skill soccer athletes than their higher-skill cohorts [83, 84].

Several more specific, predetermining factors may more predictably explain the different rates of ankle sprain. These include higher cumulative numbers of athlete exposures, greater match exposure [85], low training-to-match ratio [86], and limited warm-up or stretch period [86–88].

Preventative Measures

Reasonable measures may be implemented to mitigate modifiable risk factors and reduce the risk of ankle sprain. Several interventions have demonstrated success in achieving these goals without significant effects on quality of life or athletic performance. By increasing passive restraints to ankle inversion and enhancing postural stability, prophylactic bracing in high-risk athletes and selected military personnel can be effective in reducing the risk of primary and recurrent ankle sprain by up to 50 % [27, 67, 89]. In one prospective randomized trial, Sitler et al. [67] showed a threefold increased risk for ankle sprain among unbraced basketball players when compared to braced athletes over a 2-year time period at the USMA. Among paratroopers, a recent systematic review revealed that an external parachute ankle brace reduced all ankle injuries, including ankle sprain, by approximately half while saving between US\$0.6 and 3.4 million in direct and indirect costs [54].

Furthermore, neuromuscular training programs have also shown merit in reducing the risk of ankle sprain. In a meta-analysis, McKeon et al. [76] confirmed that prophylactic and targeted balance control training resulted in a 20–60 % relative risk reduction for sustaining lateral ankle sprain, particularly in those individuals with prior history of ankle sprain. With more consistent screening of high-risk athletes and better-instrumented measures for diagnosis, prophylactic interventions may gain more widespread popularity and effectively reduce the incidence of ankle sprain.

Osteochondral Lesions of the Talus

Introduction

Osteochondral lesions of the talus (OLTs) encompass a broad spectrum of terms previously used to describe injury to the articular talar dome, including osteochondritis dissecans, transchondral talus fractures, and osteochondral talar fractures (Figs. 11.6–11.8). An OLT can occur in association with a severe, acute ankle sprain, and the majority of patients will note an acute injury or remote history of trauma. Alternatively, an OLT can also arise from chronic ankle instability due to the repeated shear stress or edge loading of the articular surface. An estimated 50 % of all acute ankle injuries have articular cartilage injury of the talus, while up to 73 % of ankle fractures are associated with chondral lesions [90, 91]. Early descriptions identify

Fig. 11.6 Coronal CT—
osteochondral lesion of the
talus

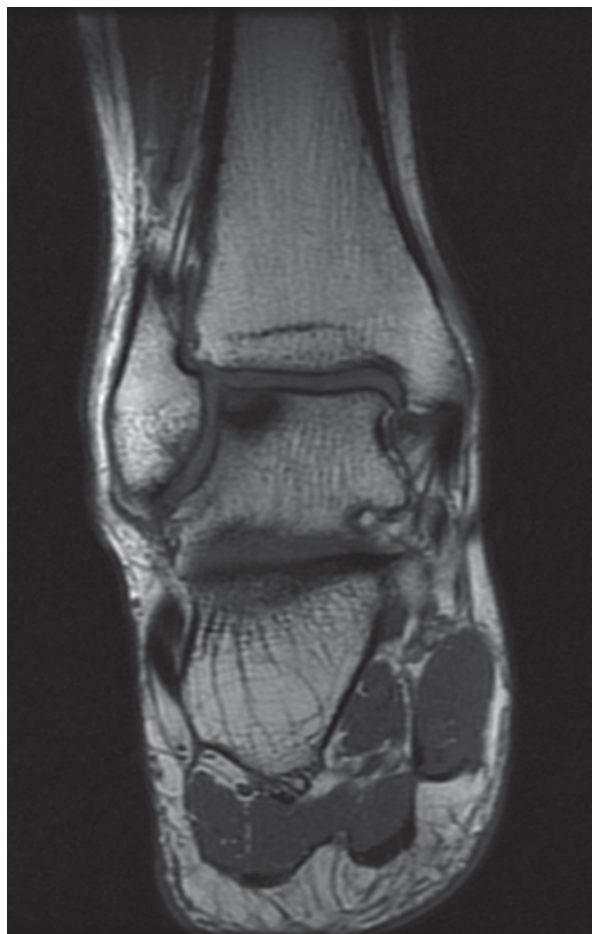


a strong association between lateral lesions of the talus and traumatic injury. Berndt and Harty [92] proposed that compression injury happens to a dorsiflexed and inverted ankle, while medial lesions can arise from inversion and external rotation onto a plantarflexed joint. However, the pathogenesis of medial OLTs is less clear and may also be associated with chronic instability, other mechanisms of injury, or atraumatic etiologies [93]. Other proposed causes include degenerative ankle arthropathy, heritable predispositions, underlying metabolic or endocrine disorders, systemic vasculopathy, joint malalignment, and excessive alcohol use [94, 95]. Due to their extensive cartilage surface, tenuous vascular supply, and limited capacity for repair, OLTs lead to chronic pain, swelling, and mechanical symptoms, while the lesion may become unstable, enlarge, or ultimately progress to osteoarthritis if left untreated [93]. Additionally, ankle synovitis, osteophyte formation, loose bodies, and peroneal tenosynovitis or tears may be present in up to 93 % of patients with chronic OLTs [96].

Epidemiology

OLTs comprise approximately only 0.1 % of all fractures of the talus and up to 0.09 % of all fractures. Approximately 6.5 % of all ankle sprains had OLTs when evaluated arthroscopically, while between 23 and 95 % of patients undergoing lateral ankle stabilization for chronic instability demonstrated chondral lesions of the talus with increased risk among athletic populations [96–99]. In a study of OLTs among the US military over a 10-year period, Orr et al. [94] reported that the unadjusted incidence rate was 27 per 100,000 person-years, with increased risk among

Fig. 11.7 Coronal T1 MRI—osteochondral lesion of the talus



individuals of female sex, white race, enlisted military rank, Army or Marine Corps service, and increasing chronological age. The authors suggest that cumulative exposure to intense occupational demands, particularly among the enlisted ranks and ground forces during a time of war, may explain the temporal and age-related trends observed in their study. Prior studies have also emphasized the increased risk of OLTs in the second to fourth decade of life, spurned by a combination of peak physical activity and age-related diminution of the biomechanical properties of articular cartilage [94, 100, 101].

As with ankle sprains, the treatment and preventative strategies for OLTs should be targeted at mitigating further ankle instability. Physical therapy, bracing, and symptomatic management with nonsteroidal, anti-inflammatory medication may limit OLT propagation or osteochondral fragment displacement, where surgical considerations for chondral restoration are more immediately appropriate (Figs. 11.9

Fig. 11.8 Coronal T2 MRI—osteochondral lesion of the talus



and 11.10). However, nonoperative management has limited success, with reported rates of acceptable outcomes ranging from 45 to 59% [102, 103].

Peroneal Tendon Pathology

Peroneal tendon pathology is associated with ankle instability or other acute ankle injury and should be suspected in any patient with chronic lateral ankle pain. Nor-

Fig. 11.9 Intraoperative arthroscopic image of lateral osteochondral lesion of the talus

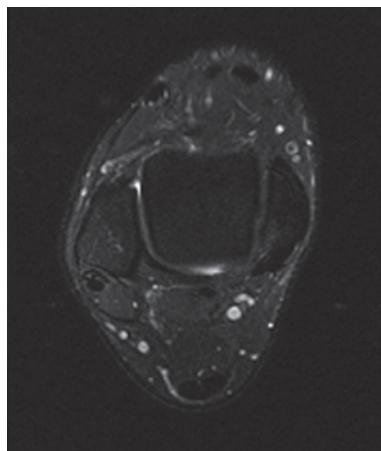


mally restrained by the superior peroneal retinaculum in the retromalleolar sulcus, the peroneus longus and brevis primarily act to plantarflex the great toe and evert the foot, respectively. In addition to these functions, the peroneal tendons also act as dynamic lateral stabilizer of the ankle, particularly during the midstance phase of gait [104]. However, the peroneal tendons can become unstable with forced dorsiflexion and eversion upon an inverted ankle, leading to tendon subluxation, longitudinal tears, and other post-traumatic tendinopathy. A low-lying peroneus brevis muscle



Fig. 11.10 Intraoperative open image of lateral osteochondral lesion of talus

Fig. 11.11 Axial T2 MRI—
peroneus brevis tear



belly, an anomalous peroneus quartus, hypertrophied peroneal tubercle, or specific anatomic variants of the retromalleolar sulcus (i.e., absent or convex morphology, calcaneal tunnel) can predispose patients to mechanical symptoms or instability, and assessment of hindfoot alignment should also be performed to rule out varus deformity as a contributing factor [105–108]. Other underlying comorbidities, including diabetes mellitus, hyperparathyroidism, rheumatoid arthritis, and psoriasis, may also contribute to peroneus longus tears, although the majority of these injuries occur during athletic injuries or other acute trauma [104] (Fig. 11.11).

Unfortunately, preventative strategies for peroneal tendon injuries are limited. Careful clinical screening and treatments focusing on the prevention of further ankle instability are the hallmarks of treatment for peroneal tendon pathology, particularly with a previous history of ankle sprain or specific underlying disease (Figs. 11.12 and 11.13).

Foot

Achilles Disorders

The gastrocnemius–soleus complex serves as a powerful plantarflexor of the ankle and provides a pivotal link to the normal gait cycle through the Achilles tendon. Given its critical importance and peak forces up to 12.5 times body weight, the Achilles tendon is often subject to several inflammatory, degenerative, and traumatic conditions, particularly with age and cumulative activity [109].

With age and repetitive loading, the microscopic architecture of the Achilles tendon undergoes characteristic changes (Fig. 11.14). The collagen fibril diameter and density decrease while becoming increasingly disorganized and disoriented. Addi-

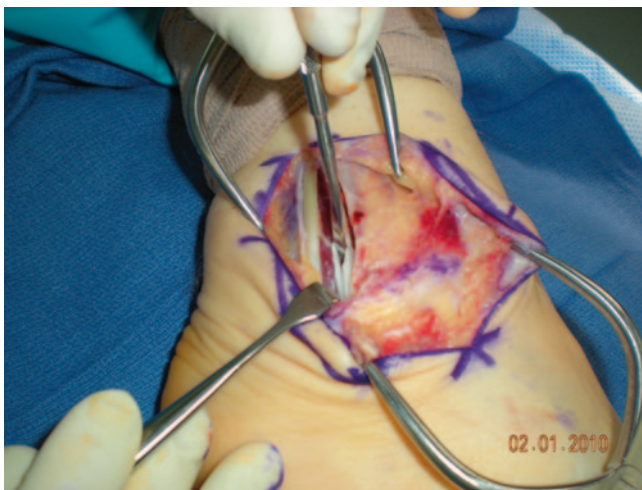


Fig. 11.12 Lateral ankle intraoperative image—longitudinal peroneus brevis tear



Fig. 11.13 Lateral ankle intraoperative image—longitudinal peroneus brevis tear

tionally, intrasubstance degeneration occurs with microtears, focal necrosis, calcification, and a relative absence of neovascularization indicative of tendinosis at the calcaneal attachment (insertional) or more proximally (non-insertional). Alternatively, tendonitis implies an underlying inflammation and is frequently a misnomer for tendinosis on histopathological analysis. Paratenonitis is an inflammatory entity that arises from mechanical irritation and manifests as edema, increased vascular re-



Fig. 11.14 Palpable Achilles tendon defect

sponse, and perivascular infiltration of inflammatory cells. Lastly, Achilles ruptures typically occur in the watershed area of limited vascularization and often vis-à-vis preexisting tendinosis.

Epidemiology

Achilles injuries are prevalent among active cohorts, particularly with running and competitive athletes, and by extension, military service members. Conservative estimates place the incidence rate of Achilles ruptures as 7 injuries per 100,000 in the general population, with increases up to 12 per 100,000 when isolating competitive athletes [110]. Although not infrequent, the epidemiology of Achilles ruptures is not completely borne out given the difficulty in quantifying a population at risk. However, certain risk factors have been articulated, including advancing age [111], male gender [112], athletic participation, involvement in selected sports (e.g., basketball) [113, 114], marked changes in training or physical activity [115], preexisting tendinopathy, steroid [116, 117] and fluoroquinolone use [118, 119], and underlying baseline comorbidities. Raikin et al. [113] conducted a descriptive epidemiological study of 406 Achilles tendon ruptures presenting to a tertiary referral setting in the USA. The patient population was middle-aged (mean, 46.4 years), male (83%), and involved in sporting activity (68%); basketball (48%) and tennis (13%) were the most commonly involved sports in related ruptures. The incidence rate among military service members is approximately 0.24% [120]. Participation in basketball has resulted in the predominance of acute Achilles ruptures, particularly among African-Americans. In their study over a 3-year time period, Davis and colleagues [114] identified that

individuals of the black race were at nearly a twofold higher risk (1.82; 95 % CI, 1.58, 2.10) of Achilles rupture than non-black patients.

Overuse Achilles injuries, including paratenonitis and symptomatic tendinopathy, are more prevalent. Both can occur with recreational or competitive athletics, although there appears to be a stronger association with endurance running. In a retrospective study of Achilles injuries, approximately 53 % of athletes were active runners at the time of injury, while an additional 27 % were involved in running sports. Of all injuries, 66 % of individuals had paratenonitis and 23 % had insertional tendinopathy. Achilles paratenonitis and symptomatic tendinopathy occur largely as a result of training errors or changes in distance, intensity, terrain, technique, or fitness. Whereas some risk factors such as misalignment, limb length inequality, and muscle imbalance or weakness are non-modifiable, other risk factors may be targets for intervention, including heel running, training surfaces, environmental conditions (e.g., wet, slippery, or uneven surfaces), footwear, and equipment [121].

Numerous approaches to conservative treatment have been postulated, although few other than an Achilles stretching and strengthening regimen have demonstrated consistent success. This preserves the mobility and function of the normal ankle and Achilles tendon, while decreasing strain. Mafi et al. [122] and Silbernagel et al. [123] demonstrated significant improvements with an eccentric, load-bearing training protocol, particularly with non-insertional tendinopathy. However, other authors have demonstrated moderate success with a limited-dorsiflexion, eccentric program in patients with insertional Achilles tendinosis as well [124].

Plantar Fasciitis

Introduction

Plantar fasciitis, an inflammatory condition affecting the attachment of the plantar fascia at the calcaneal tubercle, is the most common source of heel pain in the ambulatory setting [125]. Its hallmark pathological findings reflect the cycle of degeneration and microtrauma followed by intrinsic attempts at repair. As a result, angiofibroblastic hyperplasia, chondroid metaplasia, and varying levels of collagen necrosis are evident on histological analysis. Largely thought to result from chronic overload to the plantar fascia, plantar fasciitis can occur alongside or dovetail into other causes of heel pain, namely, nerve entrapment of the first branch of the lateral plantar nerve (i.e., Baxter's nerve). However, the pathophysiology and potential association between these conditions, as well as plantar heel spurs, remains unclear [126]. In addition to those mentioned, other sources of heel pain must also be entertained, such as seronegative enthesopathies (e.g., ankylosing spondylitis, Reiter syndrome), heel pad atrophy, infection, calcaneal stress fracture, osteoarthritis, and compressive neuropathies (e.g., tarsal tunnel syndrome).

Epidemiology

Up to 10% of the population will be affected by plantar fasciitis during their lifetime [126] and it may occur bilaterally in up to 20–30% of patients [128]. Plantar fasciitis affects two fairly distinct, yet disparate cohorts. Low-demand, sedentary individuals may develop plantar fasciitis due to cumulative or excessive loading, and obesity has been consistently identified as a potential risk factor for plantar fasciitis [129, 130] and chronic plantar heel pain [131–133] in this population. Additionally, occupations that involve prolonged standing, walking, or other upright, repetitive activity aside from athletics may also precipitate plantar fasciitis, or the British appellation “policeman’s heel” [126, 130].

Plantar fasciitis also commonly affects athletic individuals and military cohorts. A national survey estimated that 83% of patients presenting for medical treatment of plantar fasciitis were active, adult individuals, with a total of 1 million visits over a 5-year period. Among runners, the prevalence of plantar fasciitis varies from 4 to 22%, while the extent of its burden among other athletes is not currently known [134]. Among over 12 million person-years at risk in US service members, Scher et al. [135] identified an incidence rate of 10.5 per 1000 person-years, with individuals of the female sex, black race, Army service, senior officer rank, and ages less than 20 or over 40 years experiencing higher rates of plantar fasciitis. The findings presented in this study support the overload theory, with sharp increases in cumulative occupational activity leading to a higher risk of plantar fasciitis, as seen in other studies [136]. Additionally, with increasing age and years of military service, plantar fasciitis may develop in response to age-related increases in heel pad thickness with corresponding loss of elasticity, thereby translating increased tensile loads to the degenerative plantar fascia [137, 138].

While the roles of sex and race have been debated, the current literature is inconclusive. In the only military study, women demonstrated a nearly twofold greater incidence rate of plantar fasciitis [135], while other authors have demonstrated increased prevalence of heel pain among men [139, 140] and women [131, 141]. Similarly, there is no definitive evidence regarding the role of race, although Scher and colleagues [135] postulated that the higher body weights or BMI among African-Americans may lead to higher rates of plantar fasciitis.

In addition to demographic parameters, several other anatomic and dynamic musculoskeletal factors have been established for plantar fasciitis. Limited ankle dorsiflexion and heel cord tightness impart greater stress on the plantar fascia through the windlass mechanism and increased compensatory foot pronation, particularly during the toe-off phase of gait. As a result, individuals with these chronic deficits demonstrate a higher risk of secondary fasciitis [130, 142]. Dorsiflexion night splints and Achilles/plantar fascial stretching exercises are successful first-line treatments and serve as the hallmarks of nonsurgical management [126, 143, 127]. DiGiovanni et al. [144] have shown that an eccentric, non-weightbearing, tissue-specific plantar fascial stretching exercise regimen is superior to standard, weight-bearing Achilles stretching programs for plantar fasciitis, with enduring long-term benefits [145].

Other aspects of foot biomechanics may also play a role in plantar fasciitis. With a subtle cavus foot, the hindfoot and midfoot do not accommodate ground reactive forces normally, leading to increased stress at the plantar fascia. Conversely, with excessive forefoot pronation with pes planus, the plantar fascia is also under continual strain due to deficiencies in other capsuloligamentous support. In response to age-related changes in the heel and these biomechanical variants, several authors have recommended the use of shock absorbing heel cups or pads as a useful complement to activity modification in the treatment of active individuals resuming athletic activity [141, 146, 147]. Additionally, orthotics and shoe modifications have also been utilized for additional shock absorption, arch support, unloading of the plantar fascia, and limitations of the windlass mechanism [148, 149], although their long-term effectiveness [150] and necessity for custom design [146] have been disputed. Given the estimated US\$192–376 million spent on the treatment of plantar fasciitis within the USA, further investigation is required to identify the cost-effectiveness and utility of these health-care resources versus other methods of conservative care [151].

Lisfranc Injuries

Introduction

First described by a French surgeon during the Napoleonic Wars in 1815, Lisfranc injuries represent a traumatic form of midfoot instability, characteristically at the second tarsometatarsal joint and further adjacent involvement. Lisfranc injuries can occur both with a high- or low-energy mechanism of injury. In the former, a direct force or crushing injury precipitates injury to the relatively immobile midfoot and strong ligamentous attachments spanning the second metatarsal and medial cuneiform. Associated fractures are common, particularly the so-called fleck sign at the medial base of the second metatarsal [152] (Figs. 11.15–11.18). However, due to the subtle physical exam and radiographic findings with low-energy injuries, a high index of suspicion must be maintained for individuals with midfoot pain and difficulty bearing weight. Lower-energy injuries occur when a fixed forefoot is indirectly loaded with sudden forefoot abduction, dorsiflexion, or more commonly, forced plantarflexion. Axial loading of a plantarflexed foot can occur due to player contact on a planted foot during athletics, floorboard impact during motor vehicle collisions, or toe-first point of contact during a fall from height.

Epidemiology

Lisfranc injuries among athletes and active patients are not infrequent. They comprise up to only 0.2% of all fractures, and the overall annual incidence of tarsometatarsal (TMT) injuries is roughly one in 55,000 individuals [153, 154]. About

Fig. 11.15 Anterior-posterior (AP) radiograph of foot—Lisfranc injury



40–45% of injuries occur as a result of motor vehicle collisions, followed by falls from height, crush injuries, or other high-energy mechanisms [155]. However, low-energy mechanisms can contribute up to 30%, and up to 20% of Lisfranc injuries may be missed or misdiagnosed on initial presentation [156]. Injuries have been reported in athletes involved in basketball, football, soccer, gymnastics, running, and horseback riding, and these cohorts may have inherently higher rates of mid-foot sprain [156–158]. An estimated 4% of collegiate football players sustain a Lisfranc injury, and this was the second most common foot injury in this population. Males have a two- to fourfold greater incidence of Lisfranc injury, with peak incidence occurring in the third decade of life [156]. Additional demographic risk factors have not been elucidated, and no modifiable risk factors have currently been identified.



Fig. 11.16 Anterior-posterior (AP) radiograph of foot—Lisfranc injury 3 months status post open reduction internal fixation

Metatarsal Fractures

Fifth Metatarsal Base Fracture

Introduction

Fifth metatarsal fractures, either traumatic or stress-related, are typically organized anatomically into three separate groups. Zone 1 fractures represent acute injuries of the fifth metatarsal tuberosity with hindfoot inversion and avulsion of the attachment site of the lateral band of the plantar fascia. Zone 2 injuries, eponymously named Jones fractures after the British surgeon who described them in 1902, involve the metaphyseal junction of the fifth metatarsal with extension into the fourth–fifth intermetatarsal articulation. Also termed “dancer’s fractures,” zone 2 fractures typically occur with forefoot adduction with a plantarflexed ankle. Finally,

Fig. 11.17 Anterior-posterior (AP) radiograph of foot—Lisfranc injury



zone 3 fractures occur at the proximal diaphysis of the fifth metatarsal and are often stress fractures due to repetitive microtrauma. Due to their vascular watershed location, Jones fractures and zone 3 fractures are collectively considered to be high-risk fractures for poor healing and nonunion (Figs. 11.19 and 11.20).

Epidemiology

Between 70 and 90% of high-risk fifth metatarsal base fractures occur in young, active individuals between the ages of 15 and 22 years old. Young athletes involved

Fig. 11.18 Anterior-posterior (AP) radiograph of foot—Lisfranc injury, 6-month status post open reduction internal fixation



in high-demand activity are at the highest risk, particularly during a running or jumping sport [159]. Common to soccer, basketball, and football, frequent shifting, pivoting, or cutting motions in a position of plantar flexion impose a higher risk of fracture due to the propensity for lateral missteps during competition. Ekstrand and Van Dijk [160] identified that these fractures accounted for only 0.5% of injuries among elite soccer athletes, and the incidence rate was 0.04 injuries per 1000 h of at-risk exposure. Of these, 45% of patients experienced prodromal symptoms and 40% occurred during preseason activities, suggesting that marked increases in stress loading of the lateral forefoot may also contribute to this injury. Furthermore, some of these fractures in the preseason may be the result of stress changes that go unrecognized prior to complete fracture.

Anatomic alignment and disease comorbidity must also be considered. Cavovarus foot deformity, even subtle changes, may alter normal loading mechanics of the lower extremity, placing disproportionate stress about the more mobile fifth metatarsal base and predisposing it to stress-related injury [161]. As well, genu varum and chronic lateral ankle instability may also affect forefoot loading and should be considered in the patient evaluation [162]. Other neuropathic disorders, namely, hereditary sensorimotor neuropathy and advanced diabetes mellitus, may

Fig. 11.19 Oblique radiograph of foot—non-healed zone 3 base of the fifth metatarsal fracture at 3 months



lead to peroneal weakness, increased adduction forces, and altered midfoot and forefoot alignment, thus leading to increased stress upon the proximal fifth metatarsal [162]. Appropriate recognition and concomitant treatment of these risk factors may facilitate improved rates of healing and diminish chances of recurrence, particularly when coupled with intramedullary screw fixation in the high-demand individual. Additionally, lateral forefoot and hindfoot posting may mitigate reinjury of the proximal fifth metatarsal through varus unloading and may be considered in selected individuals [161].

Metatarsal Stress Fracture

Introduction

The so-called march fractures were first described among the Prussian military during the mid-1800s [162] and continue to be a notable cause of disability among

Fig. 11.20 Oblique radiograph of foot—6 months after intramedullary screw after non-healed zone 3 base of the fifth metatarsal fracture



active populations. Lesser metatarsal fractures comprise between 9 and 19% of all stress fractures [164]. However, Cosman et al. [9] identified that up to 58% of stress fractures at West Point involved the lesser metatarsals. The second (most common) and third metatarsals account for nearly 80–90% of all metatarsal stress fracture [3, 164]. In comparison to the high-risk, transverse proximal fifth metatarsal stress fracture, these fractures are typically oblique, diaphyseal injuries that are largely considered low risk (Figs. 11.21–11.24). Great toe metatarsal fractures account for only 10% of all metatarsal stress fractures and are compression-type injuries predominately seen in elderly populations or young children, sub-populations outside the scope of a typical military population [162].

Epidemiology

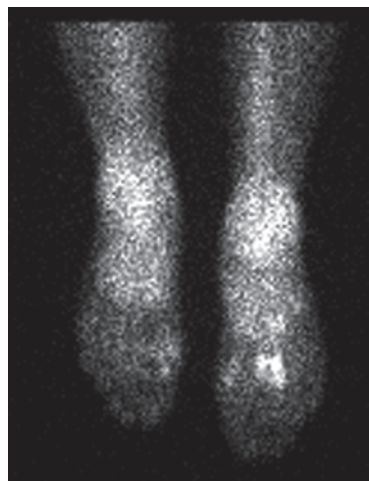
In many ways, lesser metatarsal stress fractures demonstrate a similar inherent pathophysiology, population at risk, and risk profile relative to other stress-related injuries in active patients. Repetitive overloading is implicated in “march fractures,” [163] particularly when training is formed on a hard surface and with inadequate

Fig. 11.21 Anterior-posterior (AP) radiograph of foot—third metatarsal stress fracture



footwear [4, 165]. Military personnel, running athletes, and ballet dancers have a documented history of metatarsal stress injuries [136, 166, 167]. During running, the bending strain of the second metatarsal is 6.9 times greater than that of the great toe and these tensile strains are adequate to generate fatigue failure with cumulative loading [168, 169]. Sullivan et al. [166] demonstrated that runners had a 16% incidence rate of second and third metatarsal stress fractures in their study, with a higher risk associated with greater than 20 miles per week, running on a hard surface, and changes in training (e.g., intensity, duration, volume, etc.) within the past 3 months.

Fig. 11.22 Bone scan showing uptake at third metatarsal



Biomechanical risk factors and underlying hormonal or physiologic variables must also be addressed. Forefoot overpronation, low arches, and/or pes planus can contribute to increased transfer of loading forces onto the second metatarsal when compared to a foot with a more normal arch, which may ultimately lead to stress fracture [162, 167, 170]. Similarly, disruption of normal forefoot and great toe function during the toe-off phase of gait may also lead to lesser toe stress fracture [171]. This can occur after a malunion of the first metatarsal or due to iatrogenic causes with hallux valgus surgery or inadvertent dorsiflexion with first metatarsal osteotomy. As with other stress fractures, menstrual irregularities, aberrant hormonal function, and nutritional deficiencies may also accelerate metatarsal stress injuries when exposed to repetitive loading activity [172].

Current interventions have focused on modifiable risk factors for metatarsal stress fractures, particularly training errors among military populations. Greater focus has been placed on gradually progressive increases in fitness training and periodization or strategic variances in training distance and intensity. In a study of 250 military recruits, Greaney and colleagues [165] demonstrated dramatic reductions in training-related stress fractures when converting to grass surface, modified shoe wear, and march gait retraining. Furthermore, Milgrom et al. [169] showed that training with basketball shoes modified with viscoelastic insoles virtually eliminated overuse stress injuries of the foot in the Israeli military. Simkins et al. [170] also showed reductions in stress-related metatarsal fracture within implementation of a prefabricated semirigid orthosis, with rates of injury 0 and 6% with and without the orthotic, respectively. With disrupted toe-off phase of gait or abnormal great toe contact, a Morton extension or firm medial shank may also be utilized to avoid subsequent stress injury of transfer metatarsalgia to the second and third metatarsals, especially when in conjunction with an adjacent metatarsal pad [162].

Fig. 11.23 Axial T2 MRI—third metatarsal stress fracture with increased uptake



In summary, lower extremity injuries to the shank, ankle, and foot are common in physically active military and athletic populations. Many of the common injuries that affect the lower extremity in these populations impact the tendons, ligaments, and bones. While some of these injuries are due to acute injury, many are due to chronic overuse or repetitive loading. Some of the modifiable and non-modifiable risk factors for these injuries have been identified; however, we still

Fig. 11.24 AP radiograph of foot—third metatarsal stress fracture after 2 months of bone stimulation treatment



have a rudimentary understanding of the risk factors for many of these lower extremity injuries. Furthermore, little is known about how baseline factors at the time of injury contribute to important patient outcomes following standard management strategies. As a result, further research is needed to identify those in the military that are at the greatest risk for these lower extremity injuries and to determine which treatment algorithms yield the best outcomes in this patient population.

References

1. Matheson GO, Clement DB, McKenzie DC, Taunton JE, Lloyd-Smith DR, MacIntyre JG. Stress fractures in athletes. A study of 320 cases. *Am J Sports Med.* 1987;15(1):46–58.
2. Buchholz RW, Court-Brown CM, Heckman JD, Tornetta P. Rockwood and Green's Fractures in Adults. (7th edn, Chap. 55). Philadelphia: Lippincott Williams and Wilkins; 2009.
3. Harrast MA, Colonno D. Stress fractures in runners. *Clin Sports Med.* 2010;29(3):399–416.

4. Milgrom C, Giladi M, Stein M, Kashtan H, Margulies JY, Chisin R, Steinberg R, Aharonson Z. Stress fractures in military recruits. A prospective study showing an unusually high incidence. *J Bone Joint Surg Br.* 1985;67(5):732–5.
5. Knapik JJ, Graham B, Cobbs J, Thompson D, Steelman R, Jones BH. A prospective investigation of injury incidence and injury risk factors among Army recruits in military police training. *BMC Musculoskeletal Disord.* 2013. 14(32).
6. Caesar BC, McCollum GA, Elliot R, Williams A, Calder J. Stress fractures of the tibia and medial malleolus. *Foot Ankle Clin.* 2013;18(2):339–55.
7. Armstrong DW, Rue JP, Wilckens JH, Frassica FJ. Stress fracture injury in young military men and women. *Bone.* 2004;35(3):806–16.
8. Yates B, White S. The incidence and risk factors in the development of medial tibial stress syndrome among naval recruits. *Am J Sports Med.* 2004;32(3):772–80.
9. Cosman F, Ruffing J, Zion M, Uhorchak J, Ralston S, Tendy S, McGuigan FE, Lindsay R, Nieves J. Determinants of stress fracture risk in United States Military Academy cadets. *Bone.* 2013;55(2):359–66.
10. Lee D. Stress fractures, active component. US Armed Forces, 2004–2010. *MSMR.* 2011;18(5):8–11.
11. U.S. Army Research Institute of Environmental Medicine Bone Health and Military Medical Readiness. U.S. Army Research Institute of Environmental Medicine, Natick, MA, USA; 2006.
12. Jones BH, Thacker SB, Gilchrist J, Kimsey CD, Sosin DM. Prevention of lower extremity stress fractures in athletes and soldiers: a systematic review. *Epidemiol Rev.* 2002;24(2):228–47.
13. Zahger D, Abramovitz A, Zelikovsky L, Israel O, Israel P. Stress fractures in female soldiers: an epidemiological investigation of an outbreak. *Mil Med.* 1988;153(9):448–50.
14. Knapik J, Montain SJ, McGraw S, Grier T, Ely M, Jones BH. Stress fracture risk factors in basic combat training. *Int J Sports Med.* 2012;33(11):940–6.
15. Brudvig TJ, Gudger TD, Obermeyer L. Stress fractures in 295 trainees: a one-year study of incidence as related to age, sex, and race. *Mil Med.* 1983;148(8):666–7.
16. Jones BH, Bovee MW, Harris JM, Cowan DN. Intrinsic risk factors for exercise-related injuries among male and female Army trainees. *Am J Sports Medicine.* 1993;21(5):705–10.
17. Mattila VM, Niva M, Kiuru M, Pihlajamäki H. Risk factors for bone stress injuries: a follow-up study of 102,515 person-years. *Med Sci Sports Exerc.* 39(7):1061–6.
18. Pester S, Smith PC. Stress fractures in the lower extremities of soldiers in basic training. *Orthop Rev.* 1992;21(3):297–303.
19. Protzman RR, Griffiths CG. Stress fractures in men and women undergoing military training. *J Bone Joint Surg Am.* 1977;59(6):825.
20. Wentz L, Liu PY, Haymes E, Ilich JZ. Females have a greater incidence of stress fractures than males in both military and athletic populations: a systemic review. *Mil Med.* 2011;176(4):420–30.
21. Kaufman KR, Brodine S, Shaffer R. Military training-related injuries: surveillance, research, and prevention. *Am J Prev Med.* 2000;18(3):54–63.
22. Bell NS, Mangione TW, Hemenway D, Amoroso PJ, Jones BH. High injury rates among female Army trainees: a function of gender? 2000. *AJPM.* 2000;18(3):141–6.
23. Hauret KG, Jones BH, Bullock SH, Canham-Chervak M, Canada S. Musculoskeletal injuries description of an under-recognized injury problem among military personnel. *Am J Prev Med.* 2010;28(1):61–70.
24. Finestone A, Milgrom C, Evans R, Yanovich R, Constantini N, Moran DS. Overuse injuries in female infantry recruits during low-intensity basic training. *Med Sci Sports Exerc.* 2008;40(11):630–5.
25. Yeung SS, Yeung EW, Gillespie LD. Interventions for preventing lower limb soft-tissue running injuries. *Cochrane Database Syst Rev.* 2011;6(7).

26. Lappe J, Cullen D, Haynatzki G, Recker R, Ahlf R, Thompson K. Calcium and vitamin D supplementation decreases incidence of stress fractures in female Navy recruits. *J Bone Miner Res.* 2008;23(5):741–9.
27. Rome K, Handoll HH, Ashford R. Interventions for preventing and treating stress fractures and stress reactions of bone of the lower limbs in young adults. *Cochrane Database Syst Rev.* 2005;18(2).
28. Fraipont MJ, Adamson GJ. Chronic exertional compartment syndrome. *J Am Acad Orthop Surg.* 2003;11(4):268–76.
29. Fronek J, Mubarak SJ, Hargens AR, Lee YF, Gershuni DH, Garfin SR, Akeson WH. Management of chronic exertional anterior compartment syndrome of the lower extremity. *Clin Orthop Relat Res.* 1987;220:217–27.
30. Detmer DE, Sharpe K, Sufit RL, Girdley FM. Chronic compartment syndrome: diagnosis, management, and outcomes. *Am J Sports Med.* 1985;13:162–70.
31. Edmundsson D, Toolanen G, Sojka P. Chronic compartment syndrome also affects nonathletic subjects: a prospective study of 63 cases with exercise-induced lower leg pain. *Acta Orthop.* 2007;78(1):136–42.
32. Wilder RP, Sethi S. Overuse injuries: tendinopathies, stress fractures, compartment syndrome, and shin splints. *Clin Sports Med.* 2004;23(1):55–81.
33. Ovarfördt P. Intramuscular pressure in vascular disease and compartment syndromes. Bulletin of the department of surgery. Lund: University of Lund; 1983.
34. Styf JR, Korner LM. Microcapillary infusion technique for measurement of intramuscular pressure during exercise. *Clin Orthop Relat Res.* 1986;207:253–62.
35. Tzortziou V, Maffulli N, Padhiar N. Diagnosis and management of chronic exertional compartment syndrome (CECS) in the United Kingdom. *Clin J Sport Med.* 2006;16(3):209–13.
36. Waterman BR, Laughlin M, Kilcoyne K, Cameron KL, Owens BD. Surgical treatment of chronic exertional compartment syndrome of the leg. *J Bone Joint Surg.* 2013;95:592–6.
37. Pedowitz RA, Hargens AR. Acute and chronic compartment syndromes. In: Garret WE, Speer KP, Kirendall DT, editors. *Principles and practice of orthopaedic sports medicine.* Philadelphia: Lippincott Williams & Wilkins; 2001. pp. 87–97.
38. Waterman BR, Liu J, Newcomb R, Schoenfeld AJ, Orr JD, Belmont PJ. Risk factors for chronic exertional compartment syndrome in a physical active military population. *Am J Sports Med.* 2013;41(11):2545–9.
39. Brennan FH, Kane SF. Diagnosis, treatment options, and rehabilitation of chronic lower leg exertional compartment syndrome. *Curr Sports Med Rep.* 2003;2(5):247–50.
40. Glorioso J. Exertional leg pain. In: O'Connor FG, Wilder RP, Nirschl R, editors. *Textbook of running medicine.* New York: McGraw-Hill; 2000. pp. 188–9.
41. Kirby RL, McDermott AG. Arch Phys Med Rehabil. *Arch Phys Med Rehabil.* 1983;54(7):296–9.
42. Tsiatzas D, Ghosh S, Maffulli N, King JB, Padhiar N. The effect of ankle position on intra-compartmental pressures of the leg. *Acta Orthop.* 43(1):42–8.
43. Diebal AR, Gregory R, Alitz C, Gerber JP. Effects of forefoot running on chronic exertional compartment syndrome: a case series. *Int J Sports Phys Ther.* 2011;6(4):312–21.
44. Fallat L, Grimm DJ, Saracco JA. Sprained ankle syndrome: prevalence and analysis of 639 acute injuries. *J Foot Ankle Surg.* 1998;37(4):280–5.
45. Ferran NA, Maffulli N. Epidemiology of sprains of the lateral ankle ligament complex. *Foot Ankle Clin.* 2006;11(3):659–62.
46. Waterman BR, Belmont PJ Jr, Cameron KL, et al. Epidemiology of ankle sprain at the United States military academy. *Am J Sports Med.* 2010;38(4):797–803.
47. Cordova ML, Sefton JM, Hubbard TJ. Mechanical joint laxity associated with chronic ankle instability: a systematic review. *Sports Health.* 2010;2(6):452–9.
48. Bridgman SA, Clement D, Downing A, et al. Population based epidemiology of ankle sprains attending accident and emergency units in the West Midlands of England, and a survey of UK ew. *Sports Health.* 2010;2(6):452–9.

49. Soboroff SH, Pappius EM, Komaroff AL. Benefits, risks, and costs of alternative approaches to the evaluation and treatment of severe ankle sprain. *Clin Orthop Relat Res*. 1984; 183:160-8. practice for severe ankle sprains. *Emerg Med J*. 2003;20(6):508-10.
50. Holmer P, Sondergaard L, Konradsen L, et al. Epidemiology of sprains in the lateral ankle and foot. *Foot Ankle Int*. 1994;15(2):72-4.
51. Waterman BR, Owens BD, Davey S, et al. The epidemiology of ankle sprain in the United States. *J Bone Joint Surg Am*. 2010;92(13):2279-84.
52. Lillywhite LP. Analysis of extrinsic factor associated with 379 injuries occurring during 34,236 military parachute descents. *JR Army Med Corps (London)*. 1991;137:115-21.
53. Knapik JJ, Spiess A, Swedler DI, Grier TL, Darakjy SS, Jones BH. Systematic review of the parachute ankle brace: injury risk reduction and cost effectiveness. *Am J Prev Med*. 2010;38(1):182-8.
54. Luippold RS, Sulsky SI, Amoroso PJ. Effectiveness of an external ankle brace in reducing parachuting-related ankle injuries. *Inj Prev*. 2011;17(1):58-61.
55. Williams JG. Aetiologic classification of sports injuries. *Br J Sports Med*. 1971;4:228-30.
56. Beynnon BD, Murphy DF, Alosa DM. Predictive factors for lateral ankle sprains: a literature review. *J Athl Train*. 2002;37(4):376-80.
57. Cameron KL. Time for a paradigm shift in conceptualizing risk factors in sports injury research. *J Athl Train*. 2010;45(1):58-60.
58. Gwinn DE, Wilckens JH, McDevitt ER, et al. The relative incidence of anterior cruciate ligament injury in men and women at the United States Naval Academy. *Am J Sports Med*. 2000;28(1):98-102.
59. Beynnon BD, Renstrom PA, Alosa DM, et al. Ankle ligament injury risk factors: a prospective study of college athletes. *J Orthop Res*. 2001;19(2):213-20.
60. Hosea TM, Carey CC, Harrer MF. The gender issue: epidemiology of ankle injuries in athletes who participate in basketball. *Clin Orthop*. 2000;372:45-49.
61. Frank C, Amiel D, Woo SL, Akeson W. Normal ligament properties and ligament healing. *Clin Orthop* 1985;196:15-25.
62. Ekstrand J, Gillquist J. Soccer injuries and their mechanisms: a prospective study. *Med Sci Sports Exerc*. 1983;15(3):267-70.
63. McKay GD, Goldie PA, Payne WR, Oakes BW. Ankle injuries in basketball: injury rate and risk factors. *Br J Sports Med*. 2001;35(2):103-8.
64. Milgrom C, Shlamkovitch N, Finestone A, et al. Risk factors for lateral ankle sprain: a prospective study among military recruits. *Foot Ankle*. 1991;12(1):26-30.
65. Malliaropoulos N, Ntessalen M, Papacostas E, et al. Reinjury after acute lateral ankle sprains in elite track and field athletes. *Am J Sports Med*. 2009;37(9):1755-61.
66. Tyler TF, McHugh MP, Mirabella MR, et al. Risk factors for noncontact ankle sprains in high school football players: the role of previous ankle sprains and body mass index. *Am J Sports Med*. 2006;34(3):471-5.
67. Sitler MR, Ryan J, Wheeler B, McBride J. The efficacy of a semirigid ankle stabilizer to reduce acute ankle injuries in basketball: a randomized clinical study at West Point. *Am J Sports Med*. 1994;22(4):454-61.
68. Freeman MA, Dean MR, Hanham IW. The etiology and prevention of functional instability of the foot. *J Bone Joint Surg Br*. 1965;47(4):678-85.
69. Leanderson J, Eriksson E, Nilsson C, Wykman A. Proprioception in classical ballet dancers. A prospective study of the influence of an ankle sprain on proprioception in the ankle joint. *Am J Sports Med*. 1996;24(3):370-4.
70. Leanderson J, Wykman A, Eriksson E. Ankle sprain and postural sway in basketball players. *Knee Surg Sports Traumatol Arthrosc*. 1993;1(3-4):203-5.
71. Perrin PP, Bene MC, Perrin CA, Durupt D. Ankle trauma significantly impairs posture control. a study in basketball players and controls. *Int J Sports Med*. 1997;18(5):387-92.
72. McGuine TA, Greene JJ, Best T, Levenson G. Balance as a predictor of ankle injuries in high school basketball players. *Clin Sports Med*. 2000;10(4):239-44.

73. Trojian TH, McKeag DB. Single leg balance test to identify risk of ankle sprains. *Br J Sports Med.* 2006;40(7):610–3.
74. Stecco C, Macchi V, Porzionato A, et al. The ankle retinacula: morphological evidence of the proprioceptive role of the fascial system. *Cells Tissues Organs.* 2010;192(3):200–10.
75. Riemann BL. Is there a link between chronic ankle instability and postural instability? *J Athl Train.* 2002;37(4):386–93.
76. McKeon PO, Hertel J. Systematic review of postural control and lateral ankle instability, part II. Is balance training clinically effective? *J Athl Train.* 2008;43(3):305–15.
77. Mohammadi F, Roozdar A. Effects of fatigue due to contraction of evertor muscles on the ankle joint position sense in male soccer players. *Am J Sports Med.* 2010;38(4):824–8.
78. Fong DT, Hong Y, Chan LK, et al. A systematic review on ankle injury and ankle sprain in sports. *Sports Med.* 2007;37(1):73–94.
79. Arnason A, Gudmundsson A, Dahl HA, et al. Soccer injuries in Iceland. *Scand J Med Sci Sports.* 1996;6(1):40–5.
80. Chomiak J, Junge A, Peterson L, Dvorak J. Severe injuries in football players: influencing factors. *Am J Sports Med.* 2000;28(5 Suppl):S58–68.
81. Kujala UM, Taimela S, Antti-Poika I, et al. Acute injuries in soccer, ice hockey, volleyball, basketball, judo, and karate: analysis of national registry data. *BMJ.* 1995;311(7018):1465–8.
82. Sullivan JA, Gross RH, Grana WA, et al. Evaluation of injuries in youth soccer. *Am J Sports Med.* 1980;8(5):325–7.
83. Chomiak J, Junge A, Peterson L, Dvorak J. Severe injuries in football players: influencing factors. *Am J Sports Med.* 2000;28(5 Suppl):S58–68.
84. Peterson L, Junge A, Chomiak J, et al. Incidence of football injuries and complaints in different age groups and skill-level groups. *Am J Sports Med.* 2000;28(5 Suppl):S51–7.
85. Arnason A, Gudmundsson A, Dahl HA, et al. Soccer injuries in Iceland. *Scand J Med Sci Sports.* 1996;6(1):40–5.
86. Dvorak J, Junge A, Chomiak J, et al. Risk factor analysis for injuries in football players: possibilities for a prevention program. *Am J Sports Med.* 2000;28(5 Suppl):S69–74.
87. Ekstrand J, Gillquist J, Moller M, et al. Incidence of soccer injuries and their relation to training and team success. *Am J Sports Med.* 1983;11(2):63–7.
88. Olsen OE, Myklebust G, Engebretsen L, et al. Exercises to prevent lower limb injuries in youth sports: clustered randomized controlled trial. *BMJ.* 2005;330(7489):449.
89. Frey C, Feder KS, Sleight J. Prophylactic ankle brace use in high school volleyball players. A prospective study. *Foot Ankle Int.* 2010;31(4):296–300.
90. Saxena A, Eakin C. Articular talar injuries in athletes: results of microfracture and autogenous bone graft. *Am J Sports Med.* 2007;35(10):1680–7.
91. Leontaritis N, Hinojosa L, Panchbhavi VK. Arthroscopically detected intra-articular lesions associated with acute ankle fractures. *J Bone Joint Surg.* 2009;91(2):333–9.
92. Berndt AL, Harty M. Transchondral fractures (osteochondritis dissecans) of the talus. *J Bone Joint Surg Am.* 2004;86(6):1336.
93. Stone JW. Osteochondral lesions of the talar dome. *J Am Acad Orthop Surg.* 1996;4(2):63–72.
94. Orr JD, Dawson LK, Garcia EJ, Kirk KL. Incidence of osteochondral lesions of the talus in the United States military. *Foot Ankle Int.* 2011;32(10):948–54.
95. O’Loughlin PF, Heyworth BE, Kennedy JG. Current concepts in the diagnosis and treatment of osteochondral lesions of the ankle. *Am J Sports Med.* 2010;38(2):392–404.
96. DiGiovanni BF, Fraga CJ, Cohen BE, Shereff MJ. Associated injuries found in chronic lateral ankle instability. *Foot Ankle Int.* 2000;21(10):809–15.
97. Komenda GA, Ferkel RD. Arthroscopic findings associated with the unstable ankle. *Foot Ankle Int.* 1999;20(11):708–13.
98. Schafer D, Hintermann B. Arthroscopic assessment of the chronic unstable ankle joint. *Knee Surg Sports Traumatol Arthrosc.* 1996;4(1):48–52.
99. Taga I, Shino K, Inoue M, Nakata K, Maeda A. Articular cartilage lesions in ankles with lateral ligament injury: an arthroscopic study. *Am J Sports Med.* 1993;21:120–7.

100. Chew KT, Tay E, Wong YS. Osteochondral lesions of the talus. *Ann Acad Med Singapore*. 2008;37(1):63–8.
101. Bosien WR, Staples OS, Russell SW. Residual disability following acute ankle sprains. *J Bone Joint Surg*. 1955;1(37):1237–43.
102. Shearer C, Loomer R, Clement D. Nonoperatively managed stage 5 osteochondral talar lesions. *Foot Ankle Int*. 2002;23(7):651–4.
103. Tol JL, Struijs PA, Bossuyt PM, Verhagen RA, van Dijk CN. Treatment strategies in osteochondral defects of the talar dome a systematic review. *Foot Ankle Int*. 2000;21(2):119026.
104. Philbin TM, Landis GS, Smith B. Peroneal tendon injuries. *J Am Acad Orthop Surg*. 2009;17(5):306–17.
105. Geller J, Lin S, Cordas D, Vieira P. Relationship of a low-lying muscle belly to tears of the peroneus brevis tendon. *Am J Orthop*. 2003;32(11):541–4.
106. Sobel M, Hashimoto J, Arnoczky SP, Bohn WH. The microvasculature of the sesmoid complex: its clinical significance. *Foot Ankle*. 1992;13(6):359–63.
107. Hyer CF, Dawson JM, Philbin TM, Berlet GC, Lee TH. The peroneal tubercle: description, classification, and relevance. *Foot Ankle Int*. 2005;26(11):947–50.
108. Manoli A, Graham B. The subtle cavus foot, “the underpronator.” *Foot Ankle Int*. 2005;26(3):256–63.
109. Injuries T. Basic science and clinical medicine. Edited by Maffulli N, Renstrom P, Wayne B. Leadbetter.
110. Hess GW. Achilles tendon rupture: a review of etiology, population, anatomy, risk factors, and injury prevention. *Foot Ankle Spec*. 2010;3(1):29–32.
111. Jarvinen TA, Kannus P, Maffulli N, Khan KM. Achilles tendon disorders: etiology and epidemiology. *Foot Ankle Clin*. 2005;10(2):255–66.
112. Wong J, Barrass V, Maffulli N. Quantitative review of operative and nonoperative management of achilles tendon ruptures. *Am J Sports Med*. 2002;30(4):565–75.
113. Raikin SM, Garras DN, Krapchev PV. Achilles tendon injuries in a United States population. *Foot Ankle Int*. 2013;34(4):475–80.
114. Davis JM, Mason KT, Clark DA. Achilles tendon ruptures stratified by age, race, and cause of injury among active duty US military members. *Mil Med*. 1999;164(12):872–3.
115. Maffulli N, Tallon C, Wong J, Peng Lim K, Bleakney R. No adverse effect on early weight bearing following open repair of acute tears of the Achilles tendon. *J Sports Med Phys Fit*. 2003;43(3):367–79.
116. Clark SC, Jones MW, Choudhury RR, Smith E. Bilateral patellar tendon rupture secondary to repeated local steroid injections. *J Accid Emerg Med*. 1995;12(4):300–1.
117. Newnham DM, Douglas JG, Legge JS, Friend JA. Achilles tendon rupture: an underrated complication of corticosteroid treatment. *Thorax*. 1991;46(11):853–4.
118. Stinner DJ, Orr JD, Hsu JR. Fluoroquinolone-associated bilateral patellar tendon rupture: a case report and review of the literature. *Mil Med*. 2010;175(6):457–9.
119. Wise BL, Peloquin C, Choi H, Lane NE, Zhang Y. Impact of age, sex, obesity, and steroid use on quinolone-associated tendon disorders. *Am J Med*. 2012;125(12):1228–38.
120. Owens B, Mountcastle S, White D. Racial differences in tendon rupture incidence. *Int J Sports Med*. 2007;28(7):617–20.
121. Kvist M. Achilles tendon injuries in athletes. *Sports Med*. 1994;18:173–201.
122. Mafi N, Lorentzon R, Alfredson H. Superior short-term results with eccentric calf muscle training compared to concentric training in a randomized prospective multicenter study on patients with chronic Achilles tendinosis. *Knee Surg Sports Traumatol Arthrosc*. 2001;9(1):42–7.
123. Silbernagel KG, Thomee R, Thomee P, Karlsson J. Eccentric overload training for patients with chronic Achilles tendon pain—a randomized controlled study with reliability testing of the evaluation methods. *Scan J Med Sports Sci*. 2001;11(4):197–206.
124. Jonsson P, Alfredson H, Sunding K, Fahlstrom M, Cook J. New regimen for eccentric calf-muscle training in patients with chronic insertional achilles tendinopathy: results of a pilot study. *Br J Sports Med*. 2008;42(9):746–9.

125. Singh D, Angel J, Bentley G, Trevino SG. Fortnightly review. Plantar fasciitis. *BMJ*. 1997;315(7101):172–5.
126. Gill LH. Plantar fasciitis: diagnosis and conservative management. *J Am Orthop Surg*. 1997;5(2):109–17.
127. Crawford F, Atkins D, Edwards J. Interventions for treating plantar heel pain. *Cochrane Database Syst Rev*. 2000;3:CD000416.
128. Schepesis AA, Leach RE, Gorzyca J. Plantar fasciitis. Etiology, treatment, surgical results, and review of the literature. *Clin Orthop Relat Res*. 1991;266:185–96.
129. Hill JJ, Cutting PJ. Heel pain and body weight. *Foot Ankle*. 1989;9(5):254–6.
130. Riddle DL, Pulisic M, Pidcoe P, Johnson RE. Risk factors for plantar fasciitis: a matched case-control study. *J Bone and Joint Surg*. 2003;85(5):872–7.
131. Rano JA, Fallat LM, Savoy-Moore RT. Correlation of heel pain with body mass index and other characteristics of heel pain. *J Foot Ankle Surg*. 2001;40(6):351–6.
132. Irving DB, Cook JL, Menz HB. Factors associated with chronic plantar heel pain: a systematic review. *J Sci Med Sport*. 2006;9(1–2):11–22.
133. Butterworth PA, Landorf KB, Smith SE, Menz HB. The association between body mass index and musculoskeletal foot disorders: a systematic review. *Obesity Rev*. 2012;13(7):630–42.
134. Rome K, Webb P, Unsworth A, Haslock I. Heel pad stiffness in runners with plantar heel pain. *Clin Biomech*. 2001;16(10):901–5.
135. Scher DL, Belmont PJ, Bear R, Mountcastle SB, Orr JD, Owens BD. The incidence of plantar fasciitis in the United States military. *J Bone Joint Surg*. 2009;91(12):2867–72.
136. Matheson GO, Macintyre JG, Taunton JE, Clement DB, Lloyd-Smith R. Musculoskeletal injuries associated with physical activity in older adults. *Med Sci Sports Exerc*. 1989;21(4):379–85.
137. Prichasuk S. The heel pad in plantar heel pain. *J Bone Joint Surg*. 1994;76(1):140–2.
138. Wearing SC, Smeathers JE, Yates B, Sullivan PM, Urry SR, Dubois P. Sagittal movement of the medial longitudinal arch is unchanged in plantar fasciitis. *Med Sci Sports Exerc*. 2004; 36(10):1761–7.
139. Taunton JE, Ryan MB, Clement DB, McKenzie DC, Lloyd-Smith DR, Zumbo BD. A retrospective case-control analysis of 2002 running injuries. *BJSM*. 2002;36(2):95–101.
140. Lapidus PW, Guidotti FP. Painful heel: report of 323 patients with 364 painful heels. *Clin Orthop Relat Res*. 1965;39:176–86.
141. Sobel M, Pavlov H, Geppert MJ, Thompson FM, DiCarlo EF, Davis WH. Painful os peroneum syndrome: a spectrum of conditions responsible for plantar lateral foot pain. *Foot Ankle Int*. 1994;15(3):112–24.
142. Patel A, Digiovanni B. Association between plantar fasciitis and isolated contracture of the gastrocnemius. *Foot Ankle Int*. 2011;32(1):5–8.
143. Garrett TR, Neibert PJ. The effectiveness of a gastrocnemius-soleus stretching program as a therapeutic treatment of plantar fasciitis. *J Sport Rehab*. 2013;22(4):308–12.
144. DiGiovanni BF, Nawoczenski DA, Lintal ME, Moore EA, Murray JC, Wilding GE, Baumhauer JF. Tissue-specific plantar fascia-stretching exercise enhances outcomes in patients with chronic heel pain. A prospective, randomized study. *J Bone Joint Surg Am*. 2003;85:1270–7.
145. DiGiovanni BF, Nawoczenski DA, Malay DP, Graci PA, Williams TT, Wilding GE, Baumhauer JF. Plantar fascia-specific stretching exercise improves outcomes in patients with chronic plantar fasciitis. A prospective clinical trial with two-year follow-up. *J Bone Joint Surg Am*. 2006;88(8):1775–81.
146. Pfeffer G, Bacchetti P, Deland J, et al. Comparison of custom and prefabricated orthoses in the initial treatment of proximal plantar fasciitis. *Foot Ankle Int*. 1999;20(4):214–21.
147. Wolgin M, Cook C, Graham C, Mauldin D. Conservative treatment of plantar heel pain: long-term follow up. *Foot Ankle Int*. 1994;15(3):97–102.

148. Gross MT, Byers JM, Krafft JL, Lackey EJ, Melton KM. The impact of custom semirigid foot orthotics on pain and disability for individuals with plantar fasciitis. *J Orthop Sports Phys Ther.* 2002;32(4):149–57.
149. Seligman DA, Dawson DR. Customized heel pads and soft orthotics to treat heel pain and plantar fasciitis. *Arch Phys Med Rehab.* 2003;84(10):15564–7.
150. Landorf KB, Keenan AM, Herbert RD. Effectiveness of foot orthoses to treat plantar fasciitis: a randomized trial. *Arch Int Med.* 2006;26(166):1305–10.
151. Tong KBJW, Ng EY. Preliminary investigation on the reduction of plantar loading pressure with different insole materials. *Foot.* 2010;20(1):1–6.
152. Vuori JP, Aro HT. Lisfranc joint injuries: trauma mechanisms and associated injuries. *J Trauma.* 1993;35(1):40–5.
153. Kalia V, Fishman EK, Carrino JA, Fayad LM. Epidemiology, imaging, and treatment of Lisfranc fracture-dislocations revisited. *Skeletal Radiol.* 2012;41(2):129–36.
154. Mantas JP, Burks RT. Lisfranc injuries in the athlete. *Clin Sports Med.* 1994;13(4):719–30.
155. Thompson MC, Mormino MA. Injury to the tarsometatarsal joint complex. *J Am Acad Orthop Sur.* 11:260–7.
156. DeOrio M, Erickson M, Usulli FG, Easley M. Lisfranc injuries in sport. *Foot Ankle Clin.* 2009;14:169–86.
157. Meyer SA, Callaghan JJ, Albright JP, Crowley ET, Powell JW. Midfoot sprains in collegiate football players. *Am J Sports Med.* 1994;22:392–401.
158. Curtis MJ, Myerson M, Szura B. Tarsometatarsal joint injuries in the athlete. *Am J Sports Med.* 1993;21:497–502.
159. Rhim B, Hung JC. Lisfranc injury and Jones fracture in sports. *Clin Podiatr Med Surg.* 2011;28(1):69–86.
160. Ekstrand J, Van Dijk CN. Fifth metatarsal fractures among male professional footballers: a potential career-ending disease. *BJSM.* 2013;47(12):754–8.
161. Raikin SM, Slenker N, Ratigan B. The association of a varus hindfoot and fracture of the fifth metatarsal metaphyseal-diaphyseal junction: the Jones fracture. *Am J Sports Med.* 2008;36(7):1367–72.
162. Weinfeld SB, Haddad SL, Myerson MS. Metatarsal stress fractures. *Clin Sports Med.* 1997;12(2):319–38.
163. Bernstein A, Stone JR. March fracture: a report of three hundred and seven cases and a new method of treatment. *J Bone Joint Surg.* 1944;26(4):743–50.
164. Fetzter GB, Wright RW. Metatarsal shaft fractures and fractures of the proximal fifth metatarsal. *Clin Sports Med.* 2006;25(1):139–50.
165. Greaney RB, Gerber FH, Laughlin RL, Kmet JP, Metz CD, Kilcheski TS, Rao BR, Silverman ED. Distribution and natural history of stress fractures in US Marine recruits. *Radiology.* 1983;146(2):339–46.
166. Boden BP, Osbahr DC, Jimenez C. Low-risk stress fractures. *Am J Sports Med.* 2001;29:100–11.
167. Sullivan D, Warren RF, Pavlov H, Kelman G. Stress fractures in 51 runners. *Clin Orthop Relat Res.* 1984;187:188–92.
168. Gross TS, Bunch RP. A mechanical model of metatarsal stress fracture during distance running. *Am J Sports Med.* 1989;17:669–74.
169. Milgrom C, Finestone A, Sharkey N, Hamel A, Mandes V, Burr D, Arndt A, Ekenman I. Metatarsal strains are sufficient to cause fatigue fracture during cyclic overloading. *Foot Ankle Int.* 2002;23(3):230–5.
170. Milgrom C, Simkin A, Eldad A, Nyska M, Finestone A. Using bone's adaptation ability to lower the incidence of stress fractures. *Am J Sports Med.* 2000;28:245–51.
171. Drez D, Young JC, Johnston RD, Parker WD. Metatarsal stress fractures. *Am J Sports Med.* 1980;8:123–5.
172. Kadel NJ, Teitz CC, Kronmal RA. Stress fractures in ballet dancers. *Am J Sports Med.* 1992;20:445–49.

Chapter 12

Thoracic and Lumbar Spine Injuries

Jeffrey B. Knox and Joseph Orchowski

Introduction

Military service members represent a highly active population that is regularly engaged in rigorous physical training as well as occupational activities that place significant stress on the spinal column. As such, spine conditions present a significant burden within this population and are among the leading causes of disability in both volunteer and conscript armies [1, 2]. In 2012, “back problems” were the most common condition resulting in a medical encounter, resulting in 917,738 visits of 214,210 service members [3].

This was well demonstrated in a recent study by Mydlarz et al., who performed a comprehensive surveillance of military service members presenting with degenerative disc disorders (which included lower back pain, sciatica, cervicgia, spondylolisthesis, etc...). During the study period of 2006–2010, the authors identified an incidence of 951.4 per 1000 person-years. Additionally, this was the primary diagnosis for 1,660,702 medical encounters, 68,247 lost duty days, and 11.1 % of medical discharges in the US Army [4].

Among spinal conditions, the lumbar spine represents the most common site of injury/disability among military personnel. Lumbar spine injuries were responsible for 145,324 episodes of care over a 1-year period in non-deployed military personnel [5]. Additionally, Knox et al. demonstrated an incidence rate of lower back pain requiring medical attention of 40.5 per 1000 person-years among the US military service members [6]. Childs et al. demonstrated that 15.8 % of soldiers incurred health-care costs related to low back pain over a 2-year period with a median cost of \$432 per soldier [7]. Back pain is also the cited reason behind 11 % of lost duty days in the British Army [8].

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211

Both the high incidence as well as the challenges of diagnosis were highlighted by Carragee et al. These authors performed a prospective study in which Special Operations reserve soldiers without prior history of back pain were followed and queried about low back pain in addition to their normal annual medical questionnaire. In this study, less than 3 % of soldiers reported back pain in their annual medical questionnaire despite 84 % reporting mild and 64 % moderate low back pain during the study period during the interviews.

Thoracic spine pain and injuries are much less common and much less commonly studied than similar conditions in the lumbar spine. Prevalence rates vary significantly between studies with differences in criteria for inclusion as well as population studied. Rates of thoracic pain in the military ranged from as low as 4.3 % among Naval officers [9] to as high as 32 % in fighter pilots [10].

Causes of Injury

Military service members are engaged in a variety of activities that place them at risk for back injuries. Military training is frequently cited as a cause of back pain or back injury in numerous studies. This, however, represents a broad category involving many different specific activities. Such activities include marching, drill, weapons training, field exercises, as well as fitness training. Gruhn et al. reported military training to be the cause of 37 % of back injuries seen at an Army physical therapy clinic [11]. Similarly, Strowbridge reported 30 % of back injuries resulting in a health-care visit to be caused by military training.

Carragee reported a 1/3 rate of back pain with an intensity rated over 4/10 during drill weekends in Special Operations reservists after training that involved road marches compared to 20 % in training without. Additionally, during such weekends, 25 % of soldiers reported an Oswestry Disability Index (ODI) over 10 after these training periods. The intensity of training does appear to correlate with injury risk as Carragee et al. reported a 10 % increased risk of injury and 3–4x risk of disability during periods of heavy training [12]. Also, frequent night training has been implicated in increased rates of back injury. Hou et al. demonstrated that night training more than twice per week resulted in nearly double the incidence of back pain in Chinese conscripts [13].

Within the broad category of military training, combat training and marching are frequently cited causes for low back pain. Fitness training which includes running 5 km more than three times per week was shown to increase the incidence of back pain by 80 % [13]. Grenade throwing training with greater than 200 throws per day resulted in a 1.7-fold increase in back pain rates [13].

In addition to military training activities, occupational activities attributed to the development of back pain or injury in over 50 % of cases [8]. There is a wide diversity of occupations within the military service with wide differences in risk exposure. Specifics regarding different occupations will be discussed in the next section. There are also certain activities that are associated with back pain and injury across

multiple occupations. One such high-risk occupational activity is manual handling and lifting. Lifting/handling activities are among the most common causes of injury and lost workdays with the back representing the most common site of injury [14]. Gruhn et al. reported manual handling to be the cause of 16% of back injuries presenting to a physical therapy clinic [11].

Although military service members are engaged in many occupational activities that place them at risk for back injury, a large proportion of individuals sustain injury during off-duty activities. Strowbridge et al. reported only 57% of injuries to be related to military training or work activities in a series of British soldiers with the remainder caused by off-duty activities, sporting activities, and road traffic accidents resulting in the remainder [8]. Gruhn et al. reported sporting activities to be responsible for 16% of lumbar spine injuries presenting to an Army physical therapy clinic [11].

Occupational Risk Factors

Despite being relatively common across the armed services, different occupations are subjected to dramatically different work environments and physical demands. Because of this, individuals of different occupations are subjected to significantly different risk of back injury and back pain. While occupational risk has been evaluated in multiple studies, there has been little consensus on high-risk occupations between these studies. Comparisons among the literature is challenging due to differences in definition of injury/disease, differing classifications of occupations, and difficulty in controlling for actual work environments or activities performed even among those with apparently similar occupations.

a. Infantry

The infantry represents another highly demanding occupation with significant stresses on the lower back as a result of both combat and training-related activities. Infantrymen have been shown in prior studies to have among the highest rates of musculoskeletal injury among the military. As such, it would be expected that this group would have high rates of injury and spinal disorders. However, in a military-wide study, Ernat et al. reported infantrymen to have 31% lower rates of lower back pain compared to matched controls. This difference was even more profound among infantrymen in the Marine Corps with a 41% decreased rate compared to matched non-infantry Marines. Similar findings have been demonstrated in other studies looking at different populations. Hou et al. reported on the low back pain rates among Chinese basic trainees and found those in the infantry to have the lowest rates of low back pain. The difference was significant with a 26% overall incidence, however the rate among the infantry was only 11% [13]. MacGregor et al. also demonstrated a significantly lower rate of low back pain in the infantry compared to other occupational groups in a post-deployment sample of the US Marines [15].

b. Artillery

Another occupation with significant burden of lumbar injury is artillerymen. Occupational requirements as an artillerymen include digging fighting positions and repetitive bending and lifting of artillery shells with weights often exceeding 70 lbs. Reynolds et al. evaluated the incidence of lower back injuries in artillerymen over a 1-year period. In this period, they reported an incidence of 30%, which resulted in an average 4.5 limited duty days per soldier [16].

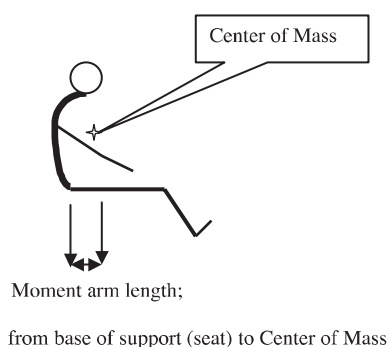
c. Aviators

Military aviators are a group with high demands placed on the spinal column. These individuals are involved in a physically demanding in poor ergonomic environments. As such, they have high rates of spinal pain and injury, particularly among helicopter pilots. Operation of rotary aircraft is particularly strenuous on the spinal column due primarily to the poor posture and awkward position required in to operate these aircraft. This includes a forward flexed posture, which induces increased thoracic kyphosis and lumbar hypolordosis. The pilots must then maintain compensatory cervical hyperextension to maintain visualization of the controls and the external environment. In addition, operating aircraft controls often requires frequent trunk rotation and lateral bending and maintenance of pelvic retroversion with notable differences between specific aircrafts [17] (Fig. 12.1).

Operating aircraft controls often requires frequent trunk rotation and lateral bending and maintenance of pelvic retroversion with notable differences between specific aircrafts (Fig 12.1).

In addition to ergonomic factors, these individuals are subjected to long periods of exposure to whole body vibration (WBV). WBV has been implicated as a potential contributing factor in the development of back pain in multiple studies [18–20], in particular when combined with awkward posture [21]. Vibratory frequency of rotary aircraft resembles the spinal resonant frequency [22, 23], which theoretically increases its potential harm. Despite this exposure, the role of WBV in the pathogenesis of back pain in this population is unclear as it is difficult to isolate WBV exposure from the exposure of flight or other aircraft-related factors.

Fig. 12.1 Seated position of pilot during flight



Shanahan et al. performed a study utilizing a helicopter cockpit with and without vibration exposure. They found no difference in back pain rates or intensity after prolonged flying with or without vibration exposure in this simulation [24].

When considering the above factors, it is not surprising that this population experiences an extremely high rate of lower back pain with rates ranging from 50 to 92% [23, 25, 26]. Back pain is also associated with significant disability and compromised mission readiness. Among pilots with back pain, approximately ½ reported interference with concentration [26] and compromised performance secondary to their pain [27]. Additionally, between 16 and 28% of pilots admit to rushing flights because of back pain [23, 26].

The pain associated with this occupation is generally felt to be directly related to the operation of the aircraft itself. Back pain typically begins during flight and in the majority of cases resolves within hours after flight is completed. Pain is more common during operations that require flying that is more dependent on manual control including precision and instrument flying. This is often more frequent in pilots greater than 71 in., which results in a more hunched-forward posture during aircraft operation. Orsello et al. demonstrated a 9% increase in incidence for every 1-in. increase in height [28].

While fixed-wing pilots also experience high rates of back pain and injury, they have been shown to have much lower rates compared to rotary-wing aircrew with a 50% lower rate reported in the Norwegian military [27]. Fighter pilots have been shown to have high rates of thoracic spine pain, with rates among the highest in the military [29].

Fixed-wing pilots are also subjected to prolonged periods of sitting in a poor ergonomic environment. Military aircraft seats are typically angled in a forward-flexed position, which places the spine in a poor position during flight. In addition, these individuals are subjected to WBV and often experience high G-forces which may also play a significant role in spinal pain or injury. While the majority of research has focused on the cervical spine in these individuals, there are significant consequences on the thoracic and lumbar spine in this population.

An additional risk, which fixed-wing aircrew are uniquely exposed to is aircraft ejection. Ejection from an aircraft subjects the spine to incredibly high forces with injury rates up to 69% [30] and vertebral fracture rates between 26.2 and 35.2% [31]. The location of injury during ejection is characteristically the thoracolumbar junction [32] with fractures occurring primarily at T12 and L1. Such fractures typically arise from a combination of axial load and forward flexion, which occurs during the ejection process [33]. This typically results in a compression-type injury, however more severe spinal fractures can occur.

It should be noticed that while the majority of research focuses on the pilots of the aircraft, the entire aircrew are at risk of back pain and injury. Flight crew, in particular the flight engineers, also encounter frequent awkward positions, which have the potential to result in back pain or injury [23, 34]. In addition, Simon-Arndt et al. demonstrated the flight engineers to have rates of diagnosed back problems higher than the pilots of the same aircraft [35].

d. Drivers

Similar to aviators, drivers have also been implicated to be at increased risk of lower back disorders. Occupational driving has been implicated in development of low back pain in multiple studies in civilian populations with anywhere from 15 to 300% increase in incidence compared to nondrivers [36–38]. Despite a high rate in such occupations, studies are limited by the diverse nature of different driving occupations including different vehicles and driving duration. Also, occupational drivers frequently perform tasks in addition to driving such heavy lifting or loading of vehicles, which would also place the back at increased risk of injury. Military vehicles, in particular, play a potential role with prolonged exposure. Such vehicles often have poor ergonomic design with significant WBV exposure [39]. Despite this, few studies have evaluated the role of occupational driving in the military.

Rozali et al. demonstrated a 73% 12-month prevalence of low back pain among Malaysian armored vehicle drivers, with rates reaching nearly 82% in drivers of tracked vehicles [39]. This study also demonstrated low back pain to be correlated with driving in a forward-flexed posture as well as WBV exposure in the x-axis. Knox et al. performed a US military-wide study to compare low back pain incidence rates between service members employed as drivers compared to matched controls. This study revealed a 15% increased risk of new onset low back pain among occupational drivers compared to controls, however they identified a much higher risk effect in female drivers who experienced a 45% increased risk compared to females in nondriving occupations [40].

e. Parachuting

Soldiers involved in military parachuting activities are another group worth special mention. Such activities subject the spinal column to significant and place these individuals at increased risk of spinal injury. Spine injuries represent the second most common type of injury after parachute jumps, and comprise 15% of acute injuries after both training and combat jumps [41]. Injuries primarily occur during landing and are related to axial load force, which often results after a hard landing on the buttocks. Traumatic vertebral fractures from such landings are typically compression fractures and occur primarily about the thoracolumbar junction [42]. In addition, the spine is subjected to deceleration forces during parachute opening.

In addition to acute traumatic events, persons engaged in repetitive parachuting activities are at relatively high risk of chronic thoracic or lumbar conditions. Murray-Leslie et al. reported on the rate of lumbar spine symptomatology as well as radiographic degeneration in ex-military parachutists. Fifty six percent of these individuals reported either current or prior lower back pain with nearly 24% having lost work time due to back pain. Additionally, 84.8% had radiographic degeneration of the lumbar spine and 21.7% had evidence of prior vertebral fractures. Interestingly, 80% of individuals with prior spine fracture were unaware of the presence of such an injury at the time of the study [42].

Military Factors

a. Branch of service

Due to differences in occupational demands as well as training regimens, differences in spine injury and disability is expected between the branches of service. Few studies have evaluated these differences as the majority of research focuses on particular groups of individuals and few have military-wide study samples. One study that evaluated a military-wide sample demonstrated significant differences in low back pain rates. In this study, the Army carried the highest incidence with a greater than twofold increased risk compared to the Navy and Marine Corps. The Navy and Marine Corps demonstrated the lowest rates with minimal differences between the two services, whereas the Air Force had an intermediate risk with approximately 50% greater risk than the Navy [6].

b. Rank

Rank is an important consideration in back injuries and has significant implications in the incidence of back disorders in military populations. The primary reason this is a consideration is that as individuals advance in rank, they often acquire more supervisory roles with potentially less rigorous activities required on a regular basis. Additionally, more senior service members often have the capability of self-modifying their training environment. This allows them to stop or decrease certain activities that are creating discomfort, whereas the more junior ranking individuals may be required to continue these activities despite the beginnings of a significant injury.

An important factor to be considered is level of education amongst these individuals. Lower level of education is a contributing factor in rates of low back pain. Individuals with an education level of bachelor's degree or higher experience have lower rates of back pain compared to those with lower levels of education [43]. As higher rank is associated with higher levels of education, this plays a potential role in the different incidence rates between ranks.

This difference in incidence between different ranks has been shown in multiple studies. In a military-wide sample, Knox et al. demonstrated significantly increased rates of low back pain in the more junior-ranking service members. This was consistent across all age groups with the highest rates in junior enlisted (E1–E4) and the lowest rate in senior officers (O4–O9) with a nearly twofold difference in incidence between these groups. MacGregor et al. also showed lower ranking Marines to have significantly higher rates of back pain after deployment to Afghanistan [15].

c. Basic training

The basic training environment represents a period of significant stress to the spinal column. Recruits are subjected to rigorous daily physical training including prolonged running, grenade throwing, marching, often with heavy combat load. In addition, recruits/conscripts are often physically deconditioned and many had led primarily sedentary lifestyles prior to this period. Wang et al. demonstrated that only 10% of the Chinese conscripts were engaged in regular physical activity or heavy

labor prior to entry into basic training [13]. As such, many such individuals lack the physical conditioning and core strength necessary to protect the spine from injury.

Because of these numerous factors, the lumbar spine represents a very common site of injury in the basic training environment [44, 45] armies. Glomsaker et al. reported that low back pain represented 18.6% of all injuries in their population with an incidence of 23.9 per 1000 conscript months. Additionally, 0.7% of trainees sustained disc herniation with a rate of 0.9 per 1000 conscript months [44]. Taanila et al. evaluated a group of Finnish conscripts over a 6-month period of training. During this period, 16% developed low back pain with an incidence rate of 1.2 per 1000 person days of training [46]. Similar rates have been shown in other studies as well [47–50].

Despite its frequency, the majority of back pain among basic trainees is self-limiting and 65% of cases will resolve by the end of the basic training period [47]. George et al. also showed that rates of low back pain with demonstrate a gradual decrease with increasing time in military service. The highest rates were seen in soldiers with less than 5 months of service, who reported back pain rates of over 55%, however this rate dropped to only 19.1% after 1 year [51]. This is likely reflective of the strenuous physical training that is encountered during basic training and the physical adaptations that occur.

Thoracic back pain is much less common, representing only 2.1% of injuries in conscripts with an incidence of only 2.7 per 1000 conscript months [44].

d. Deployment

Deployment also is a period that represents a period at high risk of developing or exacerbating lower back pain or injury. The back is the most common site of injury during deployments, representing 17.4% of musculoskeletal injuries in a series of 593 soldiers deployed to Afghanistan [52]. Lower back pain was experienced by as many as 77% of soldiers deployed to Afghanistan and 22% reported pain rated as moderate or higher [53]. Spine pain/injuries are also a common cause for evacuation representing 7.2% of evacuations from Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF).

Service members in the deployed environment are subjected to long periods of wearing body armor and combat gear, have increased duration and intensity of work, and are subjected to significant psychosocial stressors. Mydlarz showed that 68% of individuals with preexisting degenerative disc disorders experienced an exacerbation during deployment [4]. Deployment-related exacerbations were more common in the Army compared to other services, particularly those in the armor/motor transport occupational group where the risk of exacerbation approached 100%. Males and service members in the youngest (17–19 years) and the oldest (> 40 year) age groups were also more affected. Patients with preexisting disorders are also at nearly twice the risk of all-cause evacuation from theater (Odds Ratio (OR) 1.98), however less than 2% of these individuals were evacuated for lower back conditions [4].

Roy et al. evaluated the variables associated with increased rate of low back pain in deployed service members and reported body armor wear, lifting activities, walking patrols, and heavy equipment weight to be statistically significant variables associated with increased risk [53]. The most common activities resulting in spine

injury resulting in evacuation has been reported to be lifting (15%), falls (11%), and driving (8%) [54]. Work shifts have been implicated in this as well. Nevin et al. demonstrated that helicopter pilots with increased work hours during deployment have significantly higher increases in rates of lower and mid back pain compared to those who maintained the same schedules.

Another significant factor is the load carried by service members. Military forces have seen a dramatic increase in the combat loads with modern combat loads including up to 68 kg of gear depending on the individual's combat role and the mission being performed. Roy et al. demonstrated an average carrying load during deployment of 16.1% of body weight for females (maximum 32.8%) and 26.4% for males (maximum 46.5%) [52].

Carrying such loads has been shown to have numerous deleterious effects on the spine. Rodriguez-Soto et al. used upright MRI to evaluate kinematic changes in active duty Marines wearing such loads. Their study demonstrated a loss of lumbar lordosis at L4–5 and L5–S1 with an associated loss of anterior intervertebral disc height. More superior levels, however showed an increased lordosis [55]. Roy et al. [53] demonstrated significantly increased rates of low back pain with increased duration of body armor wear in deployed soldiers. In this study, wearing body armor greater than 6 h per day was associated with greater than fivefold rate of low back pain compared to those who did not wear body armor [53]. Also, increased equipment weight directly increased the incidence of back pain in this cohort with a linear increase in risk with higher weights [53]. Additionally, between 29 [56] and 41% [53] of soldiers who develop back pain during deployment attribute their pain to wearing combat gear [56].

Service members are also subjected to increased psychosocial stressors, which has been shown to be important in the development of lower back pain and conversion to chronic or recurrent pain. Shaw et al. demonstrated that coexisting anxiety disorders, PTSD, or depression significantly increases the risk of acute low back pain becoming chronic.

Due to dramatic differences in job-related activities, significant differences in injury rates are expected between occupations. MacGregor et al. reported on the rates of post-deployment lower back pain in active duty Marines. They reported the highest rates in the service/supply occupational group (OR 1.3) with Marines involved in construction-related occupations demonstrating the highest rates (8.6%). In contrast, Marine infantrymen had one of the lowest rates of lower back pain (3.3%) [15].

Midback pain represents a much less common entity experienced during deployment. While low back pain represents 75.6% of spine area pain, mid back pain represented only 3.3% in a recent study by Carragee et al. [57].

e. Reserves

Another population that deserves special mention is that of the reservist. While active duty service members are involved in regular physical conditioning and preparation for their role in their military occupation, reserve service members often lead relatively sedentary lifestyles with significantly different occupations than those

performed during their active duty obligation. As such, it could be presumed that these individuals may be at increased risk of injury or development of overuse injuries. Warr et al. reported that back injuries represented 17% of musculoskeletal injuries in deployed National Guardsmen [58]. Additionally, low back pain rates in deployed National Guardsmen (NG) was lower than active duty service members with those in active duty experiencing a 1.45-fold increased risk vs. NG. Similarly, George et al. revealed an increased rate of low back pain in active duty service members compared to reservists with a similar effect size (OR 1.441) [51].

Individual Factors

a. Gender

Gender has been implicated as a factor associated with higher rates of lower back pain in both civilian [59–64] and military service members [6, 8, 11, 15, 51, 65, 66]. Knox et al. revealed an odds ratio for females to males of low back pain resulting in a visit to a health-care provider of 1.45 compared to matched controls [6]. Strowbridge et al. revealed a much higher effect with female soldiers experiencing between 2.71 and 4.97-fold risk compared to males [8, 65]. They also reported that female soldiers more frequently attributed their low back pain to military activities, work, and off-duty activities compared to their male counterparts [8]. Gemmell demonstrated the incidence among female recruits to be significantly correlated to the training regimen. In their series, female recruits engaged in “gender fair” training with separate standards for men and women sustained 4.8-fold rate of back-related medical discharges during basic training compared to male recruits. After implementation of uniform training across genders, this rate increased to a 9.7-fold [67]. In addition to increased incidence rates, George et al. demonstrated a shorter duration to onset of low back pain in female service members [51].

b. Age

Increased age has been associated with increased prevalence of low back pain in numerous studies in civilian populations [60, 61, 63, 68]. This is due to both increased cumulative exposure to potentially injurious activities as well as age-related degenerative changes. Studies in the military setting have also shown age-related differences in back pain rates. An important consideration in the military setting is potential confounding between age and rank. As age and rank are often linked, it is important for studies to control for this to isolate the effects of age.

The age-related differences in low back pain incidence was evaluated by Knox et al., who demonstrated a bimodal distribution of back pain in this population with the highest rates in those over 40 years old as well as those less than 20⁶. This was shown after adjusting for other potential confounders including gender, branch of service, and rank. MacGregor et al. also reported higher rates of low back pain among Marines over 25 years old compared to those younger than this age in a post-deployment sample [15].

c. Race

Race is another important consideration in the epidemiology of back pain and back injury. Multiple studies on civilian populations have demonstrated significant differences in prevalence rates between racial groups. Knox et al. reviewed and evaluated the incidence of low back pain resulting in a visit to a health-care provider between different racial groups of active duty service members [69]. In their series, the lowest incidence was seen in Asian/Pacific Islanders with an incidence rate of 30.7 per 1000 person-years. Conversely, African-Americans had the highest rate of 43.7. These racial differences were present across all age groups and genders, however they showed that the effects of age and race were variable between racial groups.

d. Fitness

Personal fitness is an important consideration in the risk of back injury and subsequent disability/loss of productivity. This is evident from multiple studies that demonstrate the protective effect of core strengthening against lumbar injury and low back pain. While the military represents a population with a higher overall physical fitness, variation in fitness level has been implicated in differences in low back pain rates.

Morken et al. demonstrated low levels of physical activity to be associated with increased risk of thoracic and lumbar spine injuries among Norwegian sailors [9]. More specifically, Taanila demonstrated a higher rate of acute low back pain in conscripts with lower push-up and sit-up scores on physical fitness testing [46]. In a large study of American soldiers, George et al. found no difference in low back pain rates depending on physical fitness test scores or routine exercise. What this study did show was higher pain intensity and more psychological distress among soldiers with lower physical fitness testing scores [51]. Warr et al. also demonstrated a significant correlation between cardiorespiratory fitness (measured by peak oxygen uptake (VO₂ peak)) and the number of visits for back complaints in deployed National Guardsmen [58]. Similarly, Feuerstein et al. reported significantly increased risk of low back pain resulting in lost work time in soldiers who report only rare aerobic exercise [66].

e. BMI

Reynolds et al. identified elevated body weight (> 90 kg) to be a significant risk factor for lower back pain in active duty engineers and artillerymen resulting in a 2.5x rate compared to those less than 90 kg [16]. In their study, however, BMI was not found to significantly correlate with back injury. Taanila demonstrated a higher rate of recurrent low back pain in conscripts with elevated BMI [46]. George et al. also reported increased incidence rates with elevated BMI with an increased risk of 1.044 for each point of elevated BMI [51]. Soldiers with increased BMI also had shorter time to first onset of back pain [51].

f. Psychosocial

More recently the importance of psychosocial factors on the pathogenesis of lower back complaints has been emphasized. This remains true in studies within the military and should not be overlooked in this population.

An important consideration in military service members is the effects of psychiatric comorbidities. Concurrent psychiatric illness in evacuees from OIF/OEF results in a 31–56% decreased likelihood of return to duty [54, 70]. Among Gulf War veterans with posttraumatic stress disorder (PTSD), over 95% had continued musculoskeletal complaints [71]. Concomitant anxiety, depression, PTSD resulted in increased risk of transitioning to chronic low back pain [72].

Workplace-related factors are also important considerations in low back pain and the associated disability. Such important factors including lack of supervisor support, perceived effort at work, peer cohesion, and job stress [2, 66, 73]. Job satisfaction is correlated with a decrease in back pain. The availability of social support is also a significant predictor of disability from back pain with those reporting a complete lack of people to turn to reporting over fivefold rate of back-related disability [73].

Another contributing factor, which has been shown to be significant among civilian populations is level of education. Taanila showed higher rates of acute low back pain amongst conscripts with lower levels of education [46]. George et al. showed soldiers with lower education levels (high school or below) to have higher pain intensity, although they did not show significant differences in back pain rates in their series [51].

Combat-Related Spine Trauma

While spine trauma represents a relatively uncommon injury sustained during combat, such injuries have become more common in modern combat engagements. In combat engagements up through the first Persian Gulf War, spine trauma represented only about 1% of injuries with the exception of the invasion of Panama [74, 75]. During the invasion of Panama, this figure reached 6%, which is felt to be related to the use of nighttime parachute operations [76]. During more recent engagements, injury rates reached 5.4% in the Global War on Terror [77] and as high as 8% reported from Afghanistan [78]. While the figures quoted in these studies do not include those killed in action, the true incidence is likely much higher. This was shown recently by Schoenfeld et al., who demonstrated that 38.5% of soldiers killed in action had at least one spinal injury [79]. The dramatic increase in incidence of spinal trauma is likely related to both increased survival of combat injuries attributed to increased use of vehicular and body armor as well as advances in military medical care and the changing nature of combat and tactics used in Iraq and Afghanistan. Current conflicts have seen a dramatic rise in the use of improvised explosive devices and roadside bombs resulting in a dramatic increase in exposure to blunt force trauma and blast injuries.

Of patients with combat-related spine trauma, the majority of injuries are caused by blunt force trauma. The most common mechanism of injury is explosive trauma, which is responsible for between 43 [77, 80] and 83% [81] of injuries. Additional common causes of injury include motor vehicle collisions (29%) and gunshot

wounds (15%) [82]. Possley [80] reported that as many as 17% of spinal trauma was sustained during non-combat activities.

The lumbar spine is among the most common sites of injury, involving between 41 [77] and 45% [81] of spinal injuries. Thoracic spine injuries are less common, however the rates vary between studies. Thoracic spine injuries represent between 6 [81] and 30% [80] of combat spine injuries.

Blair et al. reported that of 2101 spinal injuries in 598 service members identified in the Joint Theater Trauma Registry, the vast majority of injuries were fractures (91.8%). A wide spectrum of injury patterns is seen. The most common injury patterns are transverse process fractures [77] and compression fractures [81]. Burst fractures represent another common type of injury, which represented 23% of injuries in one series [77].

While much less common, there are some specific injury patterns that are seen with disproportionate frequency in combat trauma. Such injuries include low lumbar burst fractures and lumbosacral dissociations [83]. While these are very rare injuries seen in the civilian population, these have been seen from more recent combat engagements. One common scenario that creates such injuries is the Improvised Explosive Device (IED) blast beneath a tactical vehicle. The result is a superior-directed blast force, which lifts the vehicle in the air. Upon landing, a significant axial force is directed to the spinal column. Additionally, service members are typically wearing rigid body armor and vehicular restraints, which provide relative stability to the thoracic and upper lumbar spine but leaves the lumbosacral junction relatively unprotected (Fig. 12.2).

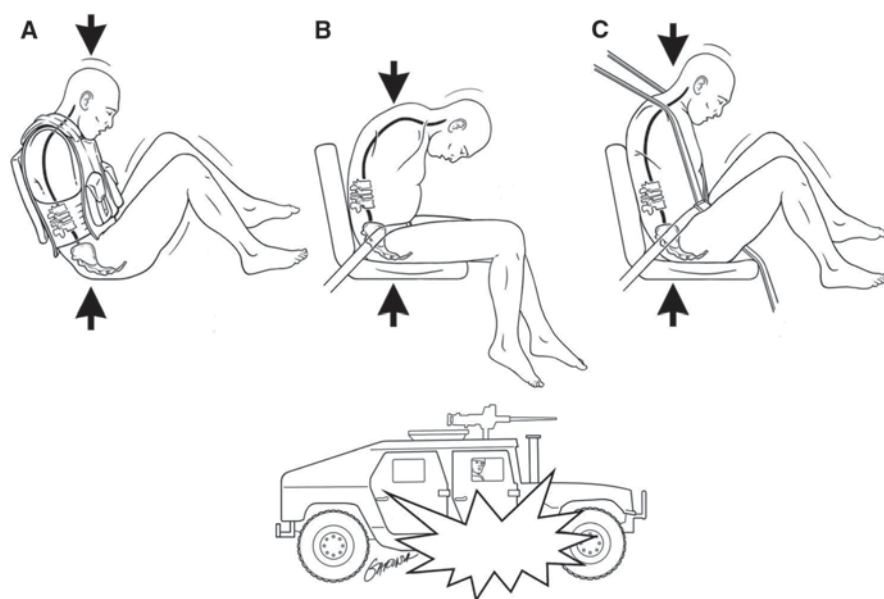


Fig. 12.2 Rigid body armor and vehicular restraints provide relative stability to the thoracic and upper lumbar spine but leaves the lumbosacral junction relatively unprotected

Overall, combat-related spine trauma represents high-energy injuries with high rates of concomitant injuries. Such concomitant injuries include open extremity fractures, traumatic amputations, as well as significant blunt or penetrating thoracic and abdominal trauma. This provides further challenges in managing these already challenging injuries. These injuries complicate both the surgical approach and also the rehabilitation. An area of particular interest specific to these injuries is the soft tissue envelope. Due to the high rate of blast injury, soft tissue injuries are common; including closed degloving injuries and contaminated complex open wounds. Attention to the soft tissue envelope is crucial in planning the approach and timing of surgical intervention as well as the need for external orthoses. Due to these complicating factors, combat-related spine trauma is associated with a significant complication rate. Possley et al. reported a 15% complication rate, with a 9% major complication rate in his series [82].

References

1. Feuerstein M, Berkowitz SM, Peck CA Jr. Musculoskeletal-related disability in US Army personnel: prevalence, gender, and military occupational specialties. *J Occup Environ Med* (American college of occupational and environmental medicine). 1997;39(1):68–78.
2. Lincoln AE, Smith GS, Amoroso PJ, Bell NS. The natural history and risk factors of musculoskeletal conditions resulting in disability among US Army personnel. *Work*. 2002;18(2):99–113.
3. Ambulatory visits among members of the active component, U.S. Armed Forces. *MSMR*. 2012 (Apr 2013);20(4):18–23; discussion 23.
4. Mydlarz D. Degenerative disc disease, active component, U.S. armed forces, 2001–2011. *MSMR*. 2012;19(5):6–9.
5. Hauret KG, Jones BH, Bullock SH, Canham-Chervak M, Canada S. Musculoskeletal injuries description of an under-recognized injury problem among military personnel. *Am J Prev Med*. 2010;38(1 Suppl):S61–S70.
6. Knox J, Orchowski J, Scher DL, Owens BD, Burks R, Belmont PJ. The incidence of low back pain in active duty United States military service members. *Spine* (Phila Pa 1976). 2011;36(18):1492–1500.
7. Childs JD, Wu SS, Teyhen DS, Robinson ME, George SZ. Prevention of low back pain in the military cluster randomized trial: effects of brief psychosocial education on total and low back pain-related health care costs. *Spine J*. 2013;14:571–83.
8. Strowbridge N. Gender differences in the cause of low back pain in British soldiers. *J R Army Med Corps*. 2005;151(2):69–72.
9. Morken T, Mageroy N, Moen BE. Physical activity is associated with a low prevalence of musculoskeletal disorders in the Royal Norwegian Navy: a cross sectional study. *BMC Musculoskelet Disord*. 2007;8:56.
10. Hamalainen O. Thoracolumbar pain among fighter pilots. *Mil Med*. 1999;164(8):595–6.
11. Gruhn J, Leggat P, Muller R. Injuries presenting to Army physiotherapy in North Queensland, Australia. *Mil Med*. 1999;164(2):145–52.
12. Carragee EJ, Cohen SP. Lifetime asymptomatic for back pain: the validity of self-report measures in soldiers. *Spine* (Phila Pa 1976). 2009;34(9):978–83.
13. Hou ZH, Shi JG, Ye H, et al. Prevalence of low back pain among soldiers at an Army base. *Chin Med J*. 2013;126(4):679–82.
14. Kemp PA, Burnham BR, Copley GB, Shim MJ. Injuries to air force personnel associated with lifting, handling, and carrying objects. *Am J Prev Med*. 2010;38(1 Suppl):S148–55.

15. MacGregor AJ, Dougherty AL, Mayo JA, Rauh MJ, Galarneau MR. Occupational correlates of low back pain among U.S. Marines following combat deployment. *Mil Med.* 2012;177(7):845–9.
16. Reynolds K, Cosio-Lima L, Creedon J, Gregg R, Zigmont T. Injury occurrence and risk factors in construction engineers and combat artillery soldiers. *Mil Med.* 2002;167(12):971–7.
17. Pelham TW, White H, Holt LE, Lee SW. The etiology of low back pain in military helicopter aviators: prevention and treatment. *Work.* 2005;24(2):101–10.
18. Lings S, Leboeuf-Yde C. Whole-body vibration and low back pain: a systematic, critical review of the epidemiological literature 1992–1999. *Int Arch Occup Environ Health.* 2000;73(5):290–7.
19. Pope MH, Wilder DG, Magnusson ML. A review of studies on seated whole body vibration and low back pain. *Proc Inst Mech Eng [H].* 1999;213(6):435–46.
20. Kasin JI, Mansfield N, Wagstaff A. Whole body vibration in helicopters: risk assessment in relation to low back pain. *Aviat Space Environ Med.* 2011;82(8):790–6.
21. Lis AM, Black KM, Korn H, Nordin M. Association between sitting and occupational LBP. *Eur Spine J.* 2007;16(2):283–98.
22. de Oliveira CG, Nadal J. Back muscle EMG of helicopter pilots in flight: effects of fatigue, vibration, and posture. *Aviat Space Environ Med.* 2004;75(4):317–22.
23. Gaydos SJ. Low back pain: considerations for rotary-wing aircrew. *Aviat Space Environ Med.* 2012;83(9):879–89.
24. Shanahan DF, Reading TE. Helicopter pilot back pain: a preliminary study. *Aviat Space Environ Med.* 1984;55(2):117–21.
25. Cunningham LK, Docherty S, Tyler AW. Prevalence of low back pain (LBP) in rotary wing aviation pilots. *Aviat Space Environ Med.* 2010;81(8):774–8.
26. Thomae MK, Porteous JE, Brock JR, Allen GD, Heller RF. Back pain in Australian military helicopter pilots: a preliminary study. *Aviat Space Environ Med.* 1998;69(5):468–73.
27. Hansen OB, Wagstaff AS. Low back pain in Norwegian helicopter aircrew. *Aviat Space Environ Med.* 2001;72(3):161–4.
28. Orsello CA, Phillips AS, Rice GM. Height and in-flight low back pain association among military helicopter pilots. *Aviat Space Environ Med.* 2013;84(1):32–7.
29. Briggs AM, Smith AJ, Straker LM, Bragge P. Thoracic spine pain in the general population: prevalence, incidence and associated factors in children, adolescents and adults. A systematic review. *BMC Musculoskelet Disord.* 2009;10:77.
30. Rotondo G. Spinal injury after ejection in jet pilots: mechanism, diagnosis, followup, and prevention. *Aviat Space Environ Med.* 1975;46(6):842–8.
31. Taneja N. Spinal disabilities in military and civil aviators. *Spine (Phila Pa 1976).* 2008;33(25):2749–53.
32. Lewis ME. Spinal injuries caused by the acceleration of ejection. *J R Army Med Corps.* 2002;148(1):22–6.
33. Hamalainen O, Visuri T, Kuronen P, Vanharanta H. Cervical disk bulges in fighter pilots. *Aviat Space Environ Med.* 1994;65(2):144–6.
34. Grant KA. Ergonomic assessment of a helicopter crew seat: the HH-60G flight engineer position. *Aviat Space Environ Med.* 2002;73(9):913–8.
35. Simon-Arndt CM, Yuan H, Hourani LL. Aircraft type and diagnosed back disorders in U.S. Navy pilots and aircrew. *Aviat Space Environ Med.* 1997;68(11):1012–8.
36. Magnusson ML, Pope MH, Wilder DG, Areskou B. Are occupational drivers at an increased risk for developing musculoskeletal disorders? *Spine (Phila Pa 1976).* 1996;21(6):710–7.
37. Waters T, Genaidy A, Barriera Viruet H, Makola M. The impact of operating heavy equipment vehicles on lower back disorders. *Ergonomics.* 2008;51(5):602–36.
38. Liira JP, Shannon HS, Chambers LW, Haines TA. Long-term back problems and physical work exposures in the 1990 Ontario health survey. *Am J Public Health.* 1996;86(3):382–7.
39. Rozali A, Rampal KG, Shamsul Bahri MT, et al. Low back pain and association with whole body vibration among military armoured vehicle drivers in Malaysia. *Med J Malaysia.* 2009;64(3):197–204.

40. Knox JBOJ, Scher DL, Owens BD, Burks R, Belmont PJ. Occupational driving as a risk factor for low back pain in active duty military service members. *Spine J*. Publication Pending.
41. Bricknell MC, Craig SC. Military parachuting injuries: a literature review. *Occup Med (Lond)*. 1999;49(1):17–26.
42. Murray-Leslie CF, Lintott DJ, Wright V. The spine in sport and veteran military parachutists. *Ann Rheum Dis*. 1977;36(4):332–42.
43. Deyo RAMS, Martin BI. Back pain prevalence and visit rates: estimates from U.S. national surveys. *Spine*. 2006;31(23):2724–7.
44. Heir T, Glomsaker P. Epidemiology of musculoskeletal injuries among Norwegian conscripts undergoing basic military training. *Scand J Med Sci Sports*. 1996;6(3):186–191.
45. Jones BH, Cowan DN, Tomlinson JP, Robinson JR, Polly DW, Frykman PN. Epidemiology of injuries associated with physical training among young men in the Army. *Med Sci Sports Exerc*. 1993;25(2):197–203.
46. Taanila HP, Suni JH, Pihlajamäki HK, et al. Predictors of low back pain in physically active conscripts with special emphasis on muscular fitness. *Spine J*. 2012;12(9):737–48.
47. Milgrom C, Finestone A, Lev B, Wiener M, Floman Y. Over exertional lumbar and thoracic back pain among recruits: a prospective study of risk factors and treatment regimens. *J Spinal Disord*. 1993;6(3):187–93.
48. O'Connor FG, Marlowe SS. Low back pain in military basic trainees. A pilot study. *Spine (Phila Pa 1976)*. 1993;18(10):1351–4.
49. Linenger JM, West LA. Epidemiology of soft-tissue/musculoskeletal injury among U.S. Marine recruits undergoing basic training. *Mil Med*. 1992;157(9):491–3.
50. Milgrom C, Finestone A, Lubovsky O, Zin D, Lahad A. A controlled randomized study of the effect of training with orthoses on the incidence of weight bearing induced back pain among infantry recruits. *Spine (Phila Pa 1976)*. 2005;30(3):272–5.
51. George SZ, Childs JD, Teyhen DS, et al. Predictors of occurrence and severity of first time low back pain episodes: findings from a military inception cohort. *PLoS One*. 2012;7(2):e30597.
52. Roy TC, Knapik JJ, Ritland BM, Murphy N, Sharp MA. Risk factors for musculoskeletal injuries for soldiers deployed to Afghanistan. *Aviat Space Environ Med*. 2012;83(11):1060–6.
53. Roy TC, Lopez HP, Piva SR. Loads worn by soldiers predict episodes of low back pain during deployment to Afghanistan. *Spine (Phila Pa 1976)*. 2013;38:1310–7.
54. Cohen SP, Nguyen C, Kapoor SG, et al. Back pain during war: an analysis of factors affecting outcome. *Arch Intern Med*. 2009;169(20):1916–23.
55. Rodriguez-Soto AE, Jaworski R, Jensen A, et al. Effect of load carriage on lumbar spine kinematics. *Spine (Phila Pa 1976)*. 2013;38(13):E783–91.
56. Konitzer LN, Fargo MV, Brininger TL, Lim Reed M. Association between back, neck, and upper extremity musculoskeletal pain and the individual body armor. *J Hand Ther Off J Am Soc Hand Ther*. 2008;21(2):143–8; quiz 149.
57. Carragee EJ. Overview of axial skeleton injuries: burden of disease. *J Am Acad Orthop Surg*. 2012;20(Suppl 1):S18–S22.
58. Warr BJ, Heumann KJ, Dodd DJ, Swan PD, Alvar BA. Injuries, changes in fitness, and medical demands in deployed National Guard soldiers. *Mil Med*. 2012;177(10):1136–42.
59. Clays EDBD, Leynen F, Kornitzer M, Kittel F, De Backer G. The impact of psychosocial factors on low back pain: longitudinal results from the Belstress study. *Spine*. 2007;32(2):262–8.
60. Gilgil EKC, Bütün B, Tuncer T, Urhan S, Yildirim C, Sünbülöglu G, Arıkan V, Tekeoglu I, Oksüz MC, Dündar U. Prevalence of low back pain in a developing urban setting. *Spine*. 2005;30(9):1093–8.
61. Bejia IYM, Jamila HB, Khalfallah T, Ben Salem K, Touzi M, Akrouit M, Bergaoui N. Prevalence and factors associated to low back pain among hospital staff. *Jt Bone Spine*. 2005;72(3):254–9.
62. Gourmelen JCJ, Ozguler A, Lanoe JL, Ravaut JF, Leclerc A. Frequency of low back pain among men and women aged 30 to 64 years in France. Results of two national surveys. *Ann Readapt Med Phys*. 2007;50(8):640–4.

63. Strine TWHJUS. National prevalence and correlates of low back and neck pain among adults. *Arthritis Rheum*. 2007;57(4):656–65.
64. Leboeuf-Yde CNJ, Kyvik K O, Fejer R, Hartvigsen J. Pain in the lumbar, thoracic or cervical regions: do age and gender matter? A population-based study of 34,902 Danish twins 20–71 years of age. *BMC Musculoskelet Disord*. 2009;10:39.
65. Strowbridge NF. Musculoskeletal injuries in female soldiers: analysis of cause and type of injury. *J R Army Med Corps*. 2002;148(3):256–8.
66. Feuerstein M, Berkowitz SM, Haufler AJ, Lopez MS, Huang GD. Working with low back pain: workplace and individual psychosocial determinants of limited duty and lost time. *Am J Ind Med*. 2001;40(6):627–38.
67. Gemmell IM. Injuries among female Army recruits: a conflict of legislation. *J R Soc Med*. 2002;95(1):23–7.
68. Hart LGDR, Charkin DC. Physician office visits of low back pain: frequency, clinical evaluation, and treatment patterns from a US national survey. *Spine*. 1995;20:11–9.
69. Knox JB, Orchowski JR, Owens B. Racial differences in the incidence of acute low back pain in United States military service members. *Spine (Phila Pa 1976)*. 2012;37(19):1688–92.
70. Cohen SP, Brown C, Kurihara C, Plunkett A, Nguyen C, Strassels SA. Diagnoses and factors associated with medical evacuation and return to duty for service members participating in operation Iraqi freedom or Operation Enduring Freedom: a prospective cohort study. *The Lancet*. 2010;375(9711):301–9.
71. Barrett DH, Doebbeling CC, Schwartz DA, et al. Posttraumatic stress disorder and self-reported physical health status among U.S. military personnel serving during the Gulf War period: a population-based study. *Psychosomatics*. 2002;43(3):195–205.
72. Shaw WS, Means-Christensen AJ, Slater MA, et al. Psychiatric disorders and risk of transition to chronicity in men with first onset low back pain. *Pain Med*. 2010;11(9):1391–400.
73. Feuerstein M, Berkowitz SM, Huang GD. Predictors of occupational low back disability: implications for secondary prevention. *J Occup Environ Med (American college of occupational and environmental medicine)*. 1999;41(12):1024–31.
74. Schoenfeld AJCPA. American combat spine surgery in the modern period (2001-present): a history and review of current literature. *J Spinal Res Found*. 2012;7(1):33–9.
75. Hardaway RM 3rd. Viet Nam wound analysis. *J Trauma*. 1978;18(9):635–43.
76. Parsons TW 3rd, Lauerman WC, Ethier DB, et al. Spine injuries in combat troops—Panama, 1989. *Mil Med*. 1993;158(7):501–2.
77. Blair JA, Patzkowski JC, Schoenfeld AJ, et al. Spinal column injuries among Americans in the global war on terrorism. *J Bone Joint Surg. Am Vol*. 2012;94(18):e135(131–9).
78. Comstock S, Pannell D, Talbot M, Compton L, Withers N, Tien HC. Spinal injuries after improvised explosive device incidents: implications for tactical combat casualty care. *J Trauma*. 2011;71(5 Suppl 1):S413–7.
79. Schoenfeld AJ, Newcomb RL, Pallis MP, et al. Characterization of spinal injuries sustained by American service members killed in Iraq and Afghanistan: a study of 2089 instances of spine trauma. *J Trauma Acute Care Surg*. 2013;74(4):1112–8.
80. Possley DR, Blair JA, Freedman BA, Schoenfeld AJ, Lehman RA, Hsu JR. The effect of vehicle protection on spine injuries in military conflict. *Spine J*. 2012;12(9):843–8.
81. Schoenfeld AJ, Goodman GP, Belmont PJ Jr. Characterization of combat-related spinal injuries sustained by a US Army Brigade Combat Team during operation Iraqi freedom. *Spine J*. 2012;12(9):771–6.
82. Possley DR, Blair JA, Schoenfeld AJ, Lehman RA, Hsu JR. Complications associated with military spine injuries. *Spine J*. 2012;12(9):756–61.
83. Helgeson MD, Lehman RA Jr, Cooper P, Frisch M, Andersen RC, Bellabarba C. Retrospective review of lumbosacral dissociations in blast injuries. *Spine (Phila Pa 1976)*. 2011;36(7):E469–75.

Chapter 13

Cervical Spine and Neck Injuries

Scott C. Wagner and Ronald A. Lehman

Introduction

History of Combat Spine Injury

Spine injuries in general have long been recognized as potentially devastating consequences of engagement in combat; indeed, the history of combat spinal injuries—and the surgeries to treat them—go back thousands of years [1–5]. There were obviously temporal confines regarding any spinal surgery given technological limitations in the centuries preceding modern times, but lifesaving combat spine surgery remains a historical reality [6]. The Edwin Smith Surgical Papyrus, one of only four surviving ancient Egyptian medial papyri, describes a number of spinal injuries incurred during combat, including cervical burst fractures and open wounds of the cervical spine [7]. The ancient Egyptians described closed reduction techniques for cervical dislocations; in the Ottoman Empire, surgeons performed posterior laminectomies for spinal decompression, and the advent of modern weaponry saw surgical removal of musket ball fragments from the spinal canal in the eighteenth century [2, 4].

The American Civil War (1861–1865) saw significant mortality, and injuries to the extremities and spine were common. Gunshot wounds to the spine, while only representing 0.26% of all injuries sustained during the conflict, were associated with a 55% mortality rate [8]. A systematic review of combat spine injuries during the Civil War, conducted by Union surgeon John Ashhurst and published in 1867, showed that only 4% of patients with spinal cord injury survived beyond 1 year [9]. Gunshots specifically to the cervical spine carried a mortality rate of 70%, and

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229

while military surgeons would continue to push the limits of “acceptable” intervention, in cases that would previously have been considered inoperable, the mortality rate remained near 40 % [10]. Overall, the mortality rate for any wound associated with a spinal cord injury approached 100 % [10, 11].

The two World Wars of the twentieth century occurred during periods of significant advances in medical and surgical care. Antiseptic principles and the addition of radiography to surgery pushed military surgeons further than had previously been thought possible, but mechanized warfare also led to dramatic changes in the type and severity of combat injury. Indeed, of the 598 documented cases of spinal wounds sustained by American military personnel on the Western Front, the mortality rate remained as high as 56 % [7].

Post-World War II conflicts, including Korea, Vietnam, Panama, Desert Storm I, and the current conflicts in Iraq and Afghanistan, have shown varied incidence of spinal injuries, primarily secondary to the development of new guerilla tactics and insurgent reliance on improvised explosive devices (IEDs) [12]. Rapid medical evacuation, which began its transformation during the Vietnam conflict with the advent of rotary wing aircraft, has significantly reduced the overall battlefield mortality rate; however, the rate of spinal injuries during the current conflict has been described as high as 7.4 %—the highest ever reported in American military medical history. Figure 13.1 compares the incidence of spine injuries as a percentage of

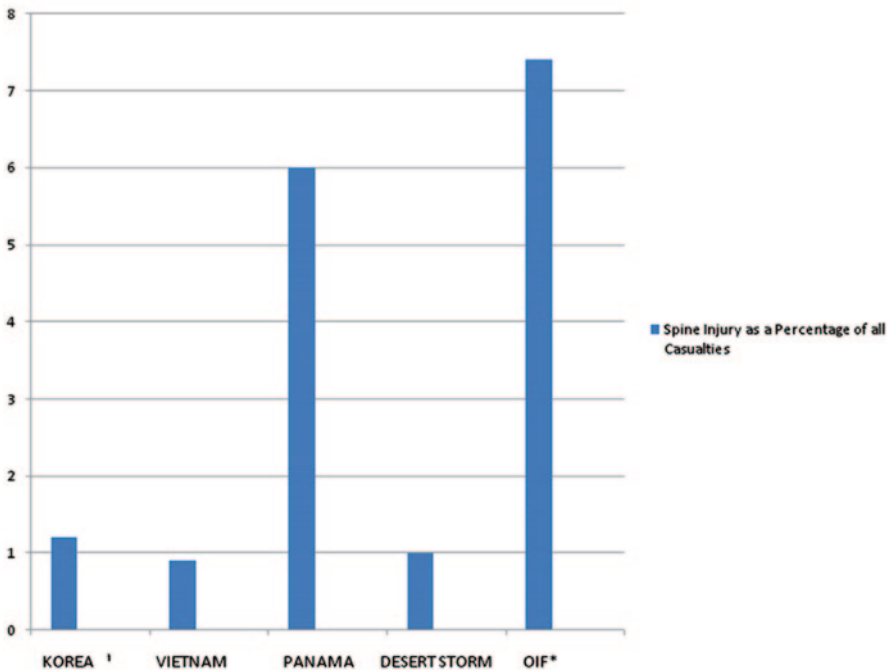


Fig. 13.1 Bar graph comparing the incidence of all spine injuries as percentage of total combat-related injuries between the Korean War and Operation Iraqi Freedom. (Reproduced from Schoenfeld [6]; with permission from Springer)

total combat casualties throughout all American conflicts since World War II. While gunshot wounds were the primary cause of combat injury in every American war throughout the twentieth century, casualties in the current conflicts most commonly result from explosions [13]; this fact is reflected in the changing patterns of cervical spine injury observed over the last decade of war.

Epidemiology of Cervical Spine Injury in the US military

Cervical spine fractures are particularly common in younger populations and are often associated with significant associated injuries [14–16]. Several modern studies, primarily from civilian trauma populations, have suggested that risk factors for cervical injury include male sex, white race, lower socioeconomic status, and age 15–30 years [17–21]. Spinal cord injury and fracture data are suggestive that, given the demographics and line of work involved, service members in the US military would be at higher risk for these injuries, which is borne out in the literature [22]. Between the years 2000 and 2009, out of over 13 million active duty service members, a total of just over 4000 cervical spine fractures were documented, with an overall incidence of 0.29 per 1000 person-years. The incidence of fracture-associated spinal cord injury was 0.07 per 1000 person-years, leading to an overall incidence of 7.4% [19]. Table 13.1 lists the overall incidence rate and risk factors for cervical spine fractures among active duty military personnel [22]. Risk factors for cervical fractures included male sex, white race, enlisted rank, and age 20–29 years, while service in the Marine Corps was identified as the highest incidence rate ratio for fracture associated with spinal cord injury.

Spine injuries sustained in direct combat during the current conflicts in Iraq and Afghanistan can be further broken down into epidemiologic categories. Utilizing the Joint Theater Trauma Registry (JTTR), the Skeletal Trauma Research Consortium reported that of 10,979 service members injured between 2001 and 2009, 598 sustained spine injuries, 86% of which were sustained from direct combat. Of these combat-related spine injuries, 14% were to the cervical spine. Figure 13.2 shows the anatomic distribution of spine injuries sustained during this time period [23]. From this study, the overall reported incidence of spinal column injuries during Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) is estimated to be 5.45%, 83% of which are results of direct combat engagement [22]. Another large, retrospective study examining spine injuries to one Army Brigade Combat Team found that the cervical spine was the more commonly injured spinal segment, occurring in 48% of all observed spine traumas. The subaxial spine (C3–C7) was most often involved [13]. Blunt trauma to the spine with a diagnosis of cervicalgia or lumbago was the most common type of injury, and 83% of these injuries were caused by a blast mechanism [13].

However, if these data are combined with information regarding spinal injuries in service members killed in action (KIA), the overall incidence rate for spinal trauma rises to 12%—much higher than previously thought and indeed the highest ever recorded in military medical history [24].

Table 13.1 The overall incidence rate and risk factors for cervical spine fractures among active duty military personnel between 2000 and 2009. Male sex, white race, and enlisted rank are all identified as significant risk factors for cervical spine fractures. (Reproduced from Schoenfeld et al. [22]; with permission from Springer)

Category	Number of cases	Person-years	Unadjusted IR ^a	Adjusted IRR (95 % CI)	<i>p</i> value
Male	3645	11,795,305	0.31	1.45 (1.31, 1.61) ^b	<0.001
Female	403	2,018,028	0.20	N/A	N/A
Black	642	2,567,557	0.25	N/A	N/A
Other	488	1,759,176	0.28	1.09 (0.97, 1.22) ^c	0.17
White	2918	9,486,600	0.31	1.21 (1.11, 1.32) ^c	<0.001
Junior enlisted	2123	6,077,634	0.35	1.63 (1.34, 1.98) ^d	<0.001
Junior officers	276	1,354,332	0.20	1.04 (0.84, 1.28) ^d	0.71
Senior enlisted	1488	5,506,970	0.27	1.42 (1.19, 1.70) ^d	<0.001
Senior officers	161	874,397	0.18	N/A	N/A
Army	1613	4,976,608	0.32	1.45 (1.33, 1.59) ^e	<0.001
Navy	968	3,549,191	0.27	1.23 (1.12, 1.35) ^e	<0.001
Air Force	750	3,484,086	0.22	N/A	N/A
Marines	717	1,803,448	0.40	1.61 (1.45, 1.79) ^e	<0.001

IRR incidence rate ratio, IR incidence rate, CI confidence interval, N/A not applicable because this category was used as the referent category for calculations

^a Incidence rate is per 1000 person-years

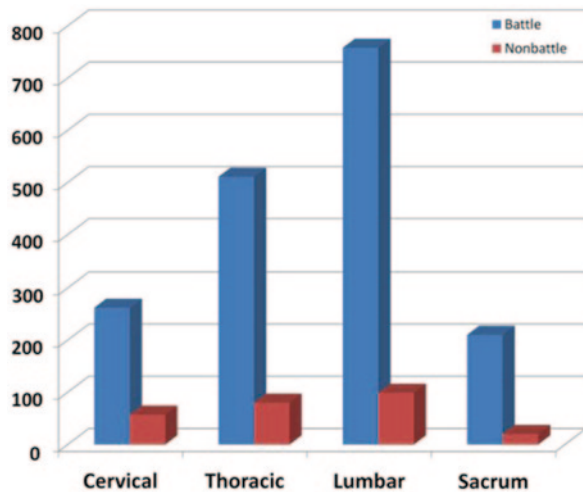
^b Adjusted for age, race, rank group, and service. Female was the referent category

^c Adjusted for age, sex, rank group, and service. Black was the referent category

^d Adjusted for age, sex, race, and service. Senior officers were the referent category

^e Adjusted for age, sex, race, and rank group. Air force was the referent category

Fig. 13.2 Bar graph depicting the anatomic distribution of spine injuries sustained during Operation Iraqi Freedom and Operation Enduring Freedom between 2001 and 2009. Cervical trauma accounts for 14% of all combat-related injuries and 21 % of all noncombat injuries. (Taken from Blair et al. [25]; with permission from Springer)



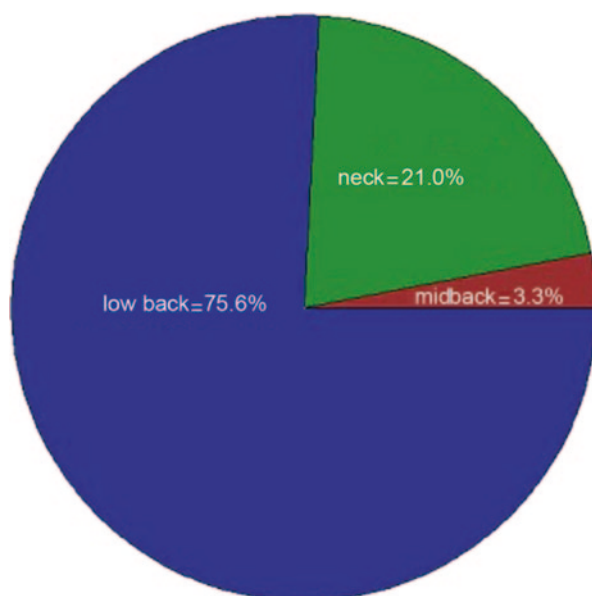
Characterization of Cervical Injuries

As we enter the second decade of the American conflicts in Iraq and Afghanistan, the burden of caring for wounded service members cannot be underestimated. The current conflicts are the longest active conflicts in American history, and as of 2013, more than 50,000 service members have been injured [26]. Indeed, it is becoming increasingly apparent that injuries to the spine—either acute traumatic injuries or chronic spinal pain—are significant contributors to this burden [27]. Patients with noncombat spine pain evacuated from theater have a less than 20 % likelihood of returning to duty [13]. It is important to recognize, therefore, that while direct trauma to the cervical spine is a significant cause of wartime morbidity and mortality, it is not the only debilitating cervical complaint observed during these long wars.

Nontraumatic Cervical Spinal Pain

By the end of the Vietnam conflict, non-battle injuries had surpassed all other disease categories as the leading cause of service member attrition [28]. In all subsequent conflicts, as the mortality rate from combat injury has steadily decreased, return to service for injured service members has become more important for maintenance of force readiness. Chronic spinal pain has become increasingly more apparent as a significant cause for hospitalization and medical evacuation from theater: over a 3-year period, almost 2500 OIF/OEF service members were medically evacuated for “spinal pain,” comprising 7.2 % of all evacuees [29]. Figure 13.3 shows the

Fig. 13.3 Pie chart showing the breakdown of spinal pain by region, with neck and cervical pain representing 21 % of all spinal complaints. (Taken from Cohen et al. [30]; with permission from Springer)



breakdown of spinal pain by region, with neck/cervical pain representing 21 % of all complaints [30]. There is some evidence suggesting that deployment to a combat zone alone increases the risk of worsening spinal pain [26]. One large epidemiologic study found that of 374 service members evacuated from theater for cervical pain, only approximately one third could identify an inciting event, the most common of which was prolonged driving [31]. Among spine pain evacuees from OIF and OEF, 84 % of service members with neck pain had primarily radicular symptomatology, suggesting that a primarily neuropathic etiology such as a herniated disc is the cause of the debilitating pain [30, 32]. Of course, the risk of spinal pain is likely multifactorial in its etiology, but its effect on force readiness and combat operations cannot be understated.

Cervical Trauma

Direct injuries to the cervical spine remain devastating realities of the current conflicts, and they do not occur in isolation. A recent retrospective study has shown that for service members sustaining any spinal injury, there is an average of 2.8 separate spine injuries per patient [22]. An understanding of the types of injuries and associated patterns sustained by service members in the current conflicts would not be complete without a discussion of the mechanisms by which a majority of these injuries occur, their other associated injuries, and their significant morbidity and mortality.

Mechanism of Injury

As previously noted in this chapter, unconventional warfare tactics, including guerrilla warfare and the use of IEDs, have been the primary modes of counterattack employed by enemy combatants. While gunshot wounds and motor vehicle collisions (MVC) remain important causes of cervical spine trauma, injuries secondary to IED blast have comprised a higher percentage of combat wounds than in any other conflict in history [33]. Advances in individual body armor as well as up-armored vehicles have increased overall survivability, but injuries remain severe [13]. Complex blast injuries have been extensively studied and have been categorized into a progressive spectrum that includes primary, secondary, tertiary, and quaternary effects [34–37]. Table 13.2 *breaks down each individual type of blast injury by effect* [38]. Specifically, injuries to the spine appear to be primarily secondary to blunt- or crush-type mechanisms rather than primary, overpressure patterns [38]. A large retrospective review of the JTTR showed that of all documented evacuated combat casualties between 2001 and 2009, 51 % of patients sustaining combat-related spine injuries were by a blunt mechanism, whereas 27 % sustained penetrating injury to the spine. However, no differentiation is made between penetrating injuries secondary to IED blast or, for example, gunshot wounds. The vast majority of these

Table 13.2 A tabular breakdown of specific injury patterns secondary to individual blast classification. (Taken from Kang et al. [38]; with permission from Springer)

Classification	Description	Injury pattern
Primary [5, 19, 22, 26, 29]	“Overpressure” injury “Implosion” occurs at time of contact with body surface, blast front rapidly compresses gas-filled organs and then near instantaneously reexpands as blast front passes “Spalling” occurs as blast front propagates through body, significant shear and stress forces because of differences in tissue density of adjacent organs and tissue at air-fluid interfaces causes forcible explosive movement of fluid from more dense to less dense tissues	<i>Implosion injuries</i> Auditory shift (2 psi) Tympanic membrane rupture (5–15 psi) Lung injury, pneumothorax, pneumomediastinum, air embolism, intestinal emphysema (30–80 psi) 50% chance of death (130–180 psi) Probable death (200–250 psi) <i>Spalling injuries</i> TBI Gastrointestinal tract injury Tearing of organ pedicle Eye injury
Secondary [5, 23, 26, 39–41]	Ballistic injury from primary bomb casing fragments; also from secondary fragments (i.e., environmental material, metallic debris, glass); become projectile after energized by explosion Fragments strike the body and cause penetrating injuries; can also cause traumatic amputations Variable velocity depending on size/shape of fragment and distance from explosion epicenter; rapid deceleration because of aerodynamic drag “Shimmy” effect from irregularly shaped fragment contacts body and exhibits tumbling; increases amount of local tissue damage	Penetrating injury Traumatic amputation Laceration TBI
Tertiary [5, 24, 28]	Whole body translocation Blast wave energizes and propels individual to tumble along the ground or thrown through air to strike hard surface Large object may become projectile and impact individual causing significant blunt or crushing injuries Crush injuries caused by structural damage and building collapse	Blunt injury Crush injury Compartment syndrome TBI
Quaternary [5]	All other explosion-related injuries	Burn injury Toxic gas or smoke inhalation injury Asphyxiation

TBI traumatic brain injury

patients sustained multiple injuries to multiple anatomic spine locations. Of patients injured by blunt mechanisms, 24% sustained isolated cervical spine injury, while 27% of those patients injured via penetrating mechanism sustained isolated cervical injury. Cervical fractures, specifically, were sustained in 18% of blunt injuries, with 21% sustaining cervical fractures in the penetrating trauma group. Transverse process and compression fractures were the most commonly observed fractures in the blunt trauma group (43%). Spinal cord injuries comprised 17% of the total patients sustaining spine trauma, with 61% of those injuries caused by a penetrating mechanism. Patients sustaining penetrating injuries were 3.8 times more likely to have a spinal cord injury than those caused by a blunt mechanism [42].

A more recent retrospective study showed that 64% of service members KIA who also had evidence of a cervical injury had vertebral fractures, and frank cervical spine transection occurred in 6% of identified cases [13]. Injuries to the atlantooccipital joint occurred in 18% of these patients, with over 97% defined as frank dislocations. Of all patients KIA with a spinal injury, 52% had at least one injury in the cervical region, and C1 was the most commonly identified level of injury to the spinal cord in 13.5% of cases—more than all observed lumbar injuries combined [13].

Associated Injuries

Although intuitive, IED blasts or other high-energy wartime injury mechanisms powerful enough to cause spinal injury also often lead to severe associated injuries. Seeking to characterize the types of injuries sustained in OIF, one large retrospective study reported a prevalence of 36.2% for injuries to the head and neck—second only to the extremities as the most commonly injured body area [39]. Another study showed concomitant injuries occurring in 74–78% of patients sustaining blunt or penetrating injuries to the spine, including chest injury, facial injury, or abdominal injuries [37]. Of patients sustaining spinal column fractures at any level, 78% also had at least one associated injury; in fact, the average number of associated injuries has been shown to be 3.37 per injured patient [43]. The most common associated injury with cervical spine trauma is traumatic brain injury (TBI), at a prevalence of 42%, but upper extremity and facial injuries were also more common in cervical trauma patients than those sustaining thoracic or lumbar injury [38]. Figure 13.4 graphically represents the percentage and distribution of patients sustaining associated injuries by spine region. Other reported associated injuries in polytraumatized patients include facial fractures, pelvic fractures, pneumothorax, and visceral trauma [13]. The overall incidence of general neck injury has been reported as 11% of all battle injuries in the armed forces of the UK, more than double of what has been reported in the USA [30]. Damage to local vascular structures, including the carotid artery or jugular vein, is associated with penetrating cervical injuries as well as airway injury [44].

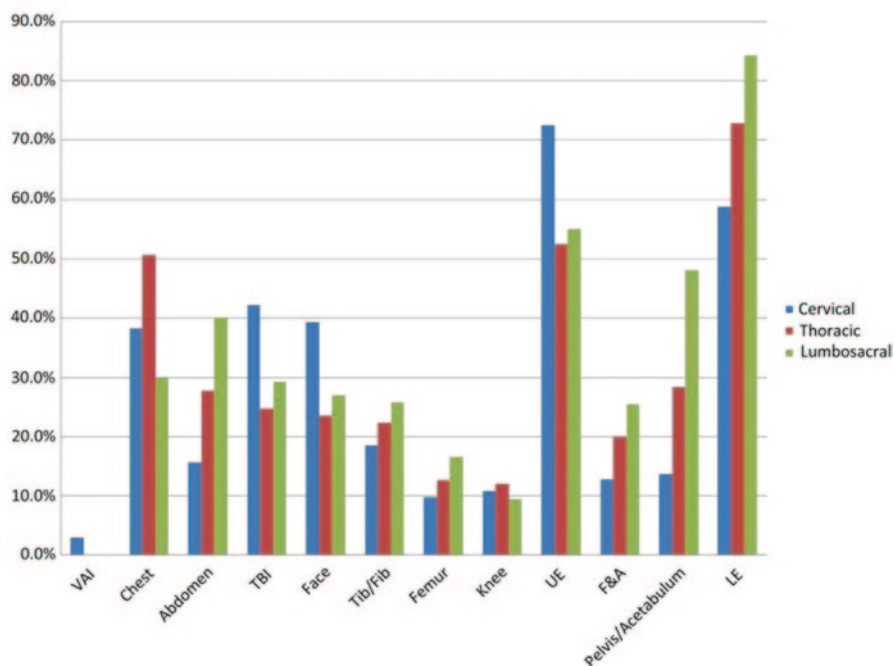


Fig. 13.4 Graphical representation of the percentage and distribution of patients sustaining associated injuries by spine region. *VAI* vertebral artery injury, *TBI* traumatic brain injury, *Tib/Fib* tibia/fibula, *UE* upper extremity, *F&A* foot and ankle, *LE* lower extremity. (Reproduced from Patzkowski et al. [43]; with permission from Springer)

Outcomes

Morbidity

As expected, given the high-energy mechanisms associated with combat trauma in these modern conflicts and their associated injuries, there is a significant morbidity and mortality burden related to cervical trauma. The most significant morbidity associated with these injuries is neurologic compromise. Long-term functional compromise remains a significant burden, despite the relatively low incidence of cervical trauma. One study, documenting the injuries observed during the civil war in former Yugoslavia, showed that 43 % of combatants sustaining spinal trauma were reported to be “severely handicapped” after their injuries [40]. As previously noted, patients with penetrating injuries to the spinal column are significantly more likely to have neurologic impairment at some level. The reported rate of improvement in neurologic function ranges from 0 to 100 % [41], with several retrospective studies citing approximately 50–60 % [23]. A significantly higher rate of neurologic improvement has been shown for service members undergoing surgical intervention for spinal cord injury sustained from non-battle-related activities as compared to

combat-related injury, suggestive that high-energy combat injuries impart significantly more damage to the spinal cord [22, 25]. With the exception of polytraumatized patients, these data do not appear to be comparable with those in the civilian literature [22, 44].

Mortality

The overall case fatality rate for service members injured in the current conflicts is the lowest in recorded history, at 10.1% [30, 34, 45]. Mortality rates for spinal trauma have been historically very high, ranging from 55% to greater than 70% [8, 9, 10] as recently as World War II and even higher in conflicts preceding it. Spine trauma in the Korean War represented 0.15% of all service members KIA [46]. While overall incidence of spine trauma during the Panama conflict was reported at only 6%, 30% of service members KIA had some form of spinal injury [47]. For the current conflicts in Iraq and Afghanistan, however, the lack of autopsy data has thus far represented a significant limitation to characterization of the overall mortality rate from spinal injuries in American military forces [13, 22]. A review of the British JTTR—which does include autopsy data—found that the most common cause of death for patients sustaining a gunshot wound to the neck during the current conflicts was cervical spinal cord injury, which occurred in 65% of those patients [48]. A recent large, retrospective review of the US Armed Forces Medical Examiner System (AFMES), which allows examination of the postmortem evaluation results of nearly all American service members KIA, showed that 38.5% of all fatalities between 2003 and 2011 had one or more spinal injuries [13]. Whether these patients expired secondary to their spinal injuries alone is not elucidated, but the expanding pool of data from the wars in Iraq and Afghanistan is beginning to suggest that the rate of spinal injury sustained in combat far exceeds that of any previous conflict in recorded history [13, 24].

Evaluation and Management of Combat Cervical Trauma

As has been discussed already in this chapter, there are several important considerations when evaluating and treating combat cervical spine injury. Currently, the Department of Defense has specific clinical practice guidelines for care provided to combat casualty patients with spinal cord injuries [49].

Echelons of Care

These guidelines are based primarily on the levels and echelons of care within the military medical evacuation system, providing recommendations with varying

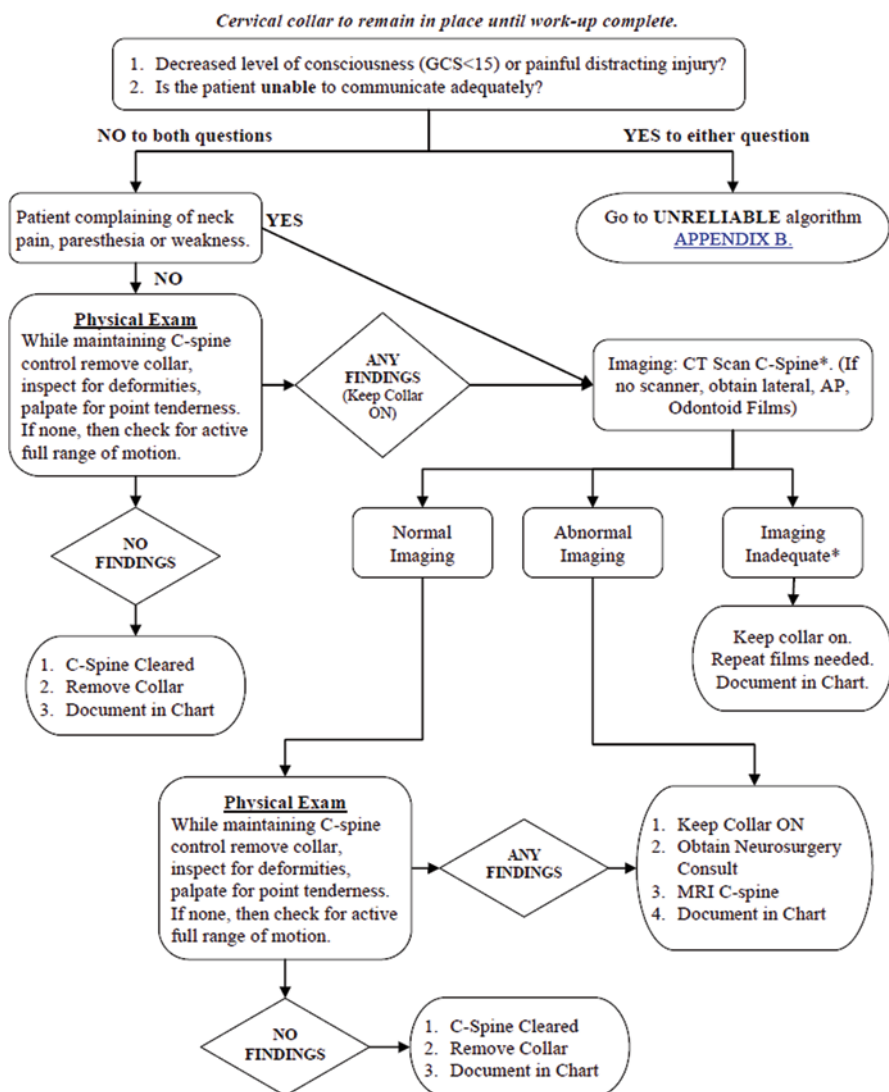
levels of evidence in support based on available medical personnel and technologies. In the military combat wounded treatment system, Echelon 1 includes treatment at the site of injury on the battlefield and subsequent transport to an aid station. The forward surgical team, comprising Echelon II, has the capability to perform life- or limb-saving surgical interventions at this level. Echelon III consists of in-theater combat support hospitals; these facilities generally have advanced imaging such as computed tomography available, but often lack specialized spine instrumentation or the personnel to provide definitive care for patients sustaining spine trauma [50]. Service members do not receive surgical implants until they reach Echelon IV (foreign military hospital) or a military treatment facility within the USA (Echelon V) [48]. Given the efficiency of the medical evacuation system, however, the transfer process often can only take 24–48 h after the injury.

Echelons I and II

The clinical practice guidelines (CPG) for cervical spine evaluation on the battlefield follow general advanced trauma life support protocols, and as in the civilian trauma setting, any patient sustaining a high-energy traumatic injury should be presumed to have a cervical spine injury until proven otherwise [51]. Any wounded service member complaining of neck pain or with neurologic compromise should be immobilized as soon as possible; however, the guidelines also state that the lives of the medical team as well as the casualty take precedence over rigid cervical immobilization, and transport of the patient to a secure or safer location is advocated to minimize the risks of further injury from enemy attack. Injured service members who sustain a secondary, penetrating injury to the neck are also at increased risk for airway compromise, and the CPG recommends clinical judgment in determining if the risk of cervical spine injury outweighs the risk of airway injury in patients who are conscious and neurologically intact [49].

Echelon III

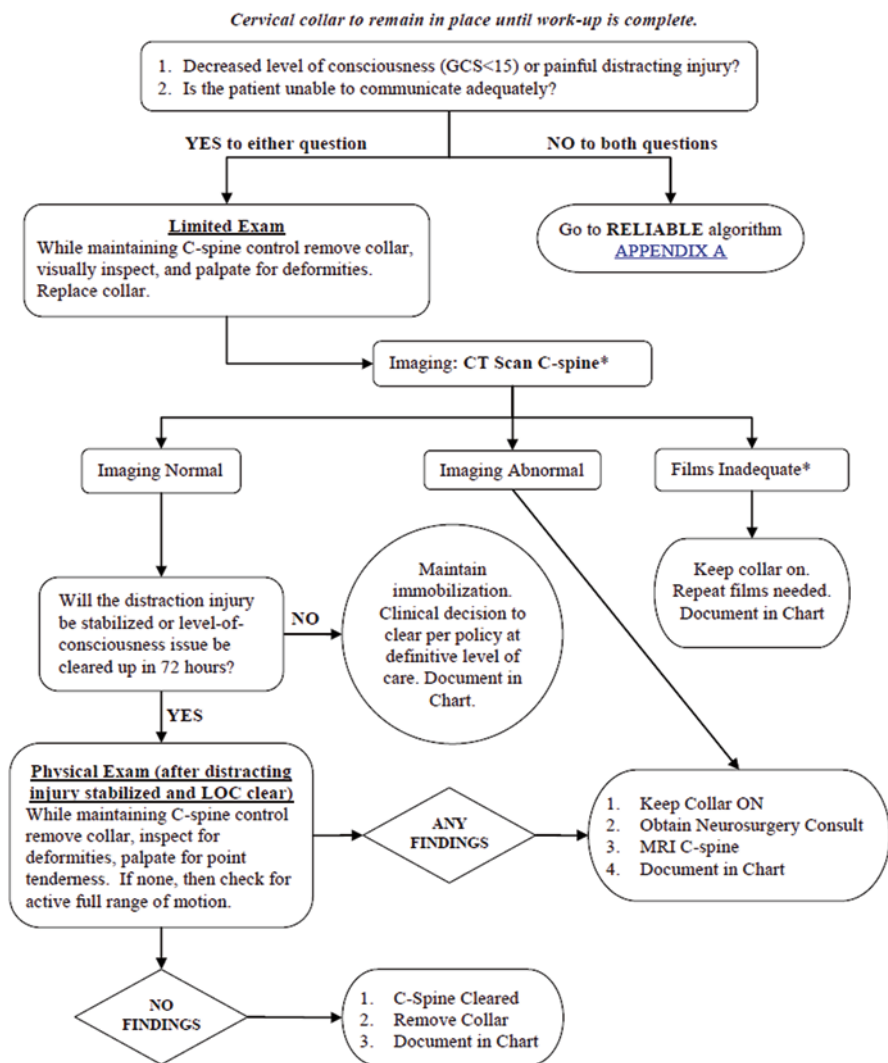
Echelon III-level care relies on the National Radiography Utilization Study criteria [52] for cervical evaluation, and algorithms have been developed based on these criteria for both conscious and unreliable patients. Figures 13.5 and 13.6 are *graphical representations of the cervical spine evaluation and clearance algorithms from the CPG* [49]. Computed tomography (CT) imaging is recommended if the patient has exam findings suggestive of or consistent with cervical injury; three views of the cervical spine (anteroposterior, lateral, and odontoid views) are allowed in the event that CT is unavailable. The collar may be removed if there are no radiographic abnormalities, but the CPG does recommend retaining the collar in cases where the patient continues to complain of neck pain or paresthesias despite normal imaging [48–50].



**Film Adequacy: Axial CT from the occiput to T1 with sagittal and coronal reconstructions.*

Fig. 13.5 Cervical spine clearance algorithm in a patient with clinically reliable exam. *CT* computed tomography, *MRI* magnetic resonance imaging, *GCS* Glasgow Coma Scale, *AP* anteroposterior. (Taken from [49])

Recommendations regarding surgical intervention for cervical spine trauma in theater are deliberately equivocal, given the limitations of operating room resources, personnel, and surgeon expertise. However, in the case of a hemodynamically stable patient with a progressive neurologic deficit, provided there is no overt contamination of the spine wound, the CPG does allow for decompression and/or instrumentation [47]. Surgical debridement and emergency decompression is recommended



**Film Adequacy: Axial CT from the occiput to T1 with sagittal and coronal reconstructions.*

Fig. 13.6 Cervical spine clearance algorithm in a patient with an unreliable physical exam. *CT* computed tomography, *MRI* magnetic resonance imaging, *GCS* Glasgow Coma Scale, *LOC* loss of consciousness. (Taken from [49])

for penetrating spinal trauma with associated cerebrospinal fluid leak, cauda equina syndrome or other progressive neurologic deficiency, and cases of incomplete spinal cord injury secondary to fragments within the spinal canal [47]. These recommendations remain highly controversial, however, as recent reviews of the current medical literature have failed to provide a consensus on the indications for acute surgical intervention in the case of penetrating spinal cord injury [40]. Despite their

findings corroborating the same, the authors of a large review article conclude that decompression should still be considered for any patient with an incomplete neurological injury and continued spinal canal compromise, ideally within 24–48 h of injury [40].

Echelons IV and V

Definitive surgical management of patients sustaining cervical trauma has typically been reserved for fully functional hospital settings in Europe or the USA, where technology and surgical expertise are more readily available [48]. Given that the vast majority of survivable cervical injuries involve transverse process or compression fractures, it logically follows that most of these patients are definitively managed without surgery [35], but it is also important to note there is a paucity of data investigating the management of combat-related cervical trauma in isolation. Review of the JTTR data has shown that patients sustaining spinal injuries from direct combat at any level are more likely to receive surgical intervention—including instrumentation, primary arthrodesis, or spinal decompression [23]. However, these patients are less likely to have partial or complete neurologic recovery than patients undergoing surgery for noncombat spinal injury [23]. It has also been reported that patients sustaining a blunt mechanism of injury to the spinal column, while having an overall lower rate of surgical intervention, demonstrated a higher rate of improvement in neurologic function as compared to patients with a penetrating mechanism of injury [35]. As previously mentioned, this fact is likely related to the fact that patients injured in combat from gunshot wounds or penetrating explosive trauma have sustained a much higher energy mechanism of injury, and these data reflect a much higher rate of instability and overall severity of injury.

Conclusion

The history of cervical spine trauma related to combat is as varied as the history of warfare itself. As the technology associated with combat has progressively become more powerful, the severity of injury has followed suit. Cervical spine trauma, however, has remained relatively constant throughout the centuries; despite affecting a small subset of wounded soldiers, cervical injury undoubtedly leads to the most devastating of outcomes and functional disability. Not all debilitating cervical symptoms are directly related to combat trauma, however, and it is important to note that even chronic cervicalgia can be exacerbated by exposure to active war zones, and while multifactorial in its etiology, it remains a significant burden to force readiness in the USA and other coalition forces. Recent studies have suggested that changing patterns of injury related to unique, modern techniques of warfare have led to a surprising increase in the incidence of spinal trauma—indeed, the rate currently recorded is the highest in human history. While maintaining one of the most

efficient and advanced medical evaluation and evacuation systems in the world, the US military must continue to confront the incapacitating effects that decades of warfare have had on its service members. Cervical trauma remains a small, but significant, piece in that puzzle.

References

1. Colton CL. The history of fracture treatment. In: Browner BD, Jupiter JB, Levine AM, Trafton PG, editors. *Skeletal trauma*. 3rd ed. Philadelphia: Saunders; 2003. p. 3e28.
2. Filler AG. A historical hypothesis of the first recorded neurosurgical operation: Isis, Osiris, Thoth, and the origin of the djed cross. *Neurosurg Focus*. 2007;23:E6.
3. Gabriel RA, Metz KS. *Contributions in military studies: a history of military medicine*. New York: Greenwood Press; 1992.
4. Goodrich JT. History of spine surgery in the ancient and medieval worlds. *Neurosurg Focus*. 2004;16:E2.
5. Kumar K. Spinal deformity and axial traction. Historical perspective. *Spine*. 1996;21:653e5.
6. Schoenfeld AJ, Belmont PJ, Weiner BK. A history of military spine surgery. *Spine J*. 2012;12:729–36.
7. Breasted JH. *The Edwin Smith surgical papyrus*. Chicago: University of Chicago Press; 1930.
8. Hanigan WC, Sloffer C. Nelson's wound: treatment of spinal cord injury in 19th and early 20th century military conflicts. *Neurosurg Focus*. 2004;16:E4.
9. Hays I, ed. *The American journal of the medical sciences*. Philadelphia: Henry C. Lea; 1867.
10. Otis GA, ed. *The medical and surgical history of the War of the Rebellion (1861–1865)*. Surgical history. Volume II. Washington, DC: GPO; 1870.
11. Otis G. *Surgical cases treated in the Army of the United States from 1865–1871*. Washington, DC: Government Printing Office; 1871.
12. Belmont PJ Jr., Schoenfeld AJ, Goodman GP. Epidemiology of combat wounds in operation Iraqi freedom and Operation Enduring Freedom: orthopaedic burden of disease. *J Orthop Surg Adv*. 2010;19:2e7.
13. Schoenfeld AJ, et al. Characterization of combat-related spinal injuries sustained by a US Army Brigade Combat Team during operation Iraqi freedom. *Spine J*. 2012;12:771–6.
14. Bohlman HH. Acute fractures and dislocations of the cervical spine. *J Bone Joint Surg Am*. 1979;61:1119–42.
15. Demetriades D, Charalambides K, Chahwan S, et al. Nonskeletal cervical spine injuries: epidemiology and diagnostic pitfalls. *J Trauma*. 2000;48:724–7.
16. Ryan MD, Henderson JJ. The epidemiology of fractures and fracture dislocations of the cervical spine. *Injury* 1992;23:38–40.
17. Burney RE, Maio RF, Maynard F, Karunas R. Incidence, characteristics, and outcome of spinal cord injury at trauma centers in North America. *Arch Surg*. 1993;128:596–9.
18. Dryden DM, Saunders LD, Rowe BH, et al. The epidemiology of traumatic spinal cord injury in Alberta, Canada. *Can J Neurol Sci*. 2003;30:113–21.
19. Hu R, Mustard CA, Burns C. Epidemiology of incident spinal fracture in a complete population. *Spine*. 1996;21:492–9.
20. Jackson AB, Dijkers M, Devivo M, Poczatek RB. A demographic profile of new traumatic spinal cord injuries: change and stability over 30 years. *Arch Phys Med Rehabil*. 2004;85:1740–8.
21. Lowery DW, Wald MM, Browne BJ, et al. NEXUS Group. Epidemiology of cervical spine injury victims. *Ann Emerg Med*. 2001;38:12–6.

22. Schoenfeld AJ, Sielski B, Rivera KP, Bader JO, Harris MB. Epidemiology of cervical spine fractures in the US military. *Spine J.* 2012;12(9):777–83.
23. Kahraman S, Gonul E, Kayali H, et al. Retrospective analysis of spinal missile injuries. *Neurosurg Rev.* 2004;27:42–5.
24. Schoenfeld AJ, et al. Characterization of spinal injuries sustained by American service members killed in Iraq and Afghanistan: a study of 2089 instances of spine trauma. *J Trauma Acute Care Surg.* 2013;74(4):1112–8.
25. Blair JA, et al. Are spine injuries sustained in battle truly different? *Spaine J.* 2012;12:824–9.
26. Department of Defense. “Operation Enduring Freedom (OEF) U.S. Casualty Status” and “Operation Iraqi Freedom (OEF) U.S. Casualty Status” Fatalities as of February 5, 2013, 10 a.m. EDT. 2013. <http://www.defense.gov/news/casualty.pdf>. Accessed 6 Jan 2013.
27. Carragee, EJ. Marching home again (Editorial): spine casualties, combat exposure, and the long wars. *Spine J.* 2012;12:723–6.
28. Hoefler DF, Melton LJ. Changes in the distribution of Navy and Marine Corps casualties from World War I through the Vietnam conflict. *Mil Med.* 1981;146:776–9.
29. Cohen SP, Brown C, Kurihara C, et al. Diagnoses and factors associated with medical evacuation and return to duty for service members participating in operation Iraqi freedom or Operation Enduring Freedom: a prospective cohort study. *Lancet.* 2010;375:301–9.
30. Cohen SP, Gallagher RM, Davis SA, Griffith SR, Carragee EJ. Spine-area pain in military personnel: a review of epidemiology, etiology, diagnosis, and treatment. *Spine J.* 2012;12:833–42.
31. Cohen SP, Kapoor SG, Nguyen C, et al. Neck pain during combat operations: an epidemiological study analyzing clinical and prognostic factors. *Spine.* 2010;35:758–63.
32. Cohen SP, Nguyen C, Kapoor SG, et al. Back pain during war: an analysis of factors affecting outcome. *Arch Intern Med.* 2009;169:1916–23.
33. Owens BD, Kragh JF Jr, Wenke JC, Macaitis J, Wade CE, Holcomb JB. Combat wounds in operation Iraqi freedom and Operation Enduring Freedom. *J Trauma.* 2008;64(2):295–9.
34. Champion HR, Holcomb JB, Young LA. Injuries from explosions: physics, biophysics, pathology, and required research focus. *J Trauma.* 2009;66:1468–77. (discussion 1477)
35. DePalma RG, Burris DG, Champion HR, Hodgson MJ. Blast injuries. *N Engl J Med.* 2005;352:1335–42.
36. Hayda R, Harris RM, Bass CD. Blast injury research: modeling injury effects of landmines, bullets, and bombs. *Clin Orthop Relat Res.* 2004;422:97–108.
37. Ramasamy A, Hill AM, Clasper JC. Improvised explosive devices: pathophysiology, injury profiles and current medical management. *J R Army Med Corps.* 2009;155:265–72.
38. Kang DG, et al. Wartime spine injuries: understanding the improvised explosive device and biophysics of blast trauma. *Spine J.* 2012;12:849–57.
39. Belmont PJ, et al. Incidence and epidemiology of combat injuries sustained during “the surge” portion of operation Iraqi freedom by a U.S. Army Brigade Combat Team. *J Trauma.* 2010;68(1):204–10.
40. Jankovic S, Busic Z, Primorac D. Spine and spinal cord war injuries during the war in Croatia. *Mil Med.* 1998;163:847–9.
41. Klimo P Jr, Ragel BT, Rosner M, et al. Can surgery improve neurological function in penetrating spinal injury? A review of the military and civilian literature and treatment recommendations for military neurosurgeons. *Neurosurg Focus.* 2010;28:E4.
42. Blair JA, et al. Military penetrating spine injuries compared with blunt. *Spaine J.* 2012;12:762–8.
43. Patzkowski JC, et al. Multiple associated injuries are common with spine fractures during war. *Spine J.* 2012;12:791–7.
44. Pirouzmand F. Epidemiological trends of spine and spinal cord injuries in the largest Canadian adult trauma center from 1986 to 2006. *J Neurosurg Spine.* 2010;12:131–40.
45. Holcomb JB, Stansbury LG, Champion HR, et al. Understanding combat casualty care statistics. *J Trauma.* 2006;60:397–401.

46. Reister FA. Battle casualties and medical statistics: U.S. Army experience in the Korean war. Washington, DC: Surgeon General, Department of the Army; 1973.
47. Parsons TW 3rd, Laueran WC, Ethier DB, et al. Spine injuries in combat troops—Panama, 1989. *Mil Med.* 1993;158:501–2.
48. Breeze J, et al. Mortality and morbidity from combat neck injury. *J Trauma.* 2012;72(4):969–74.
49. Joint Theater Trauma System Clinical Practice Guideline: Cervical and Thoracolumbar spine injury: Surgical Management and Transport. 2012. http://www.usaisr.amedd.army.mil/assets/cpgs/Cervical_and_Thoracolumbar_Spine_Injury_9_Mar_12.pdf. Accessed 6 Jan 2013.
50. Burris DG, Dougherty PJ, Elliot DC, et al. eds. Emergency war surgery. Washington, DC: Borden Institute, Walter Reed Army Medical Center; 2004.
51. Joint Theater Trauma System Clinical Practice Guideline: Cervical spine evaluation and non-surgical management. 2012. http://www.usaisr.amedd.army.mil/assets/cpgs/Cervical_Spine_Evaluation_19_Mar_12.pdf. Accessed 6 Jan 2013.
52. Hoffman JR, Mower WR, Wolfson AB, et al. Validity of a set of clinical criteria to rule out injury to the cervical spine in patients with blunt trauma: National Emergency X-Radiography Utilization Study Group. *N Engl J Med.* 2000;343:94–9.

Part III
Public Health Strategies for Injury
Prevention and Treatment in the Military

Chapter 14

Application of the Public Health Model for Musculoskeletal Injury Prevention Within the Military

Kenneth L. Cameron

List of Acronyms

AFEB Armed Forces Epidemiological Board
DoD Department of Defense
DMSS Defense Medical Surveillance System

Introduction

Throughout history, effective military commanders have understood that maintaining the health of their soldiers is critical to their success on the battlefield [1, 2]. Early public health and preventive medicine efforts within armies can be traced back thousands of years and are referenced in the Old Testament [3]. These early public health practices focused on regulating diet, monitoring the safety of food and water sources, maintaining personal hygiene, recognizing and investigating disease outbreaks, and providing guidance to military commanders on all aspects of force health protection and camp sanitation in the field [3]. In the American military, similar preventive medicine and public health functions have been reported from the Revolutionary War through the recent conflicts in Iraq and Afghanistan [4, 3, 5, 6].

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249

Officially sanctioned public health functions in the US military can be traced back over more than 70 years when the Army Industrial Hygiene Laboratory was established at the beginning of World War II at the Johns Hopkins School of Hygiene and Public Health [7]. These early public health functions in the military were focused on occupational health in the Department of Defense (DoD) production base but quickly expanded to include preventive medicine functions focused on force health protection [3, 7]. Initial public health and preventive medicine initiatives in the military were primarily focused on the prevention of infectious and communicable diseases [1, 8, 9].

In 1953 the Armed Forces Epidemiological Board (AFEB) was formed. The board comprised civilian physicians, epidemiologists, public health officials, and other scientists, and their primary function was to provide consultation to the assistant secretary of defense for health affairs and the surgeon general of the Army, Navy, and Air Force [8]. Much of the early public health focus of this group was also on the prevention of infectious disease; however, this recently shifted to focus more on preventing injuries and musculoskeletal conditions in the military [8-12]. In the early 1990s, leaders within the DoD began to develop an increased appreciation for the impact that musculoskeletal injuries and conditions have on military readiness [8, 11]. As a result, the AFEB established the Injury Prevention and Control Working Group [8]. This group comprised military and civilian physicians, epidemiologists, and other key scientists and was tasked with reviewing existing injury data within the military and making recommendations for improving injury surveillance and prevention strategies within this high-risk population [8]. This seminal work applied the public health model to examine the burden of injuries within the military population [12] and yielded important recommendations for improved injury surveillance and prevention efforts [8, 11, 12]. One of the most important accomplishments of the working group was to bring light to the “hidden epidemic” of musculoskeletal injuries and conditions within military populations [9, 11]. Subsequent initiatives have continued to apply the public health model to better understand the scope of musculoskeletal injuries in this high-risk population and to evaluate the efficacy and effectiveness of prevention efforts. The US Army Public Health Command was established in 2011, and part of the organization’s core mission is to promote health and prevent disease, injury, and disability among soldiers, retirees, family members, and DoD civilians [13].

The purpose of this chapter is to provide an overview of how the public health model has been applied to define the “hidden epidemic” [8, 9, 11, 12] of musculoskeletal injuries and conditions in the military and how it is being used to develop and implement evidence-based injury prevention interventions in this high-risk population. Subsequent chapters in this part focus on evidence-based injury prevention strategies that have been applied within the military population (Chap. 15) and discuss a framework for effective injury prevention, as well as strategies to overcome barriers to effective injury prevention in the military environment (Chap. 16).

Early Application of the Public Health Model for Injuries in the Military

The AFEB and the Injury Prevention and Control Working Group initially adopted a five-step public health model, which was adapted from other sources, as a framework to systematically evaluate the burden of injuries within the military population [12]. The group was specifically interested in determining how military medical information could be used for injury surveillance and to inform public health practice related to injury prevention. The five steps in the public health model were: (1) Determine the existence and magnitude of the problem, (2) identify causes of the problem, (3) determine what prevents the problem, (4) implement prevention strategies and programs, and (5) continue surveillance and monitor/evaluate the effectiveness of prevention efforts [12]. While all steps are critical, it is important to note that the steps in the public health approach to injury prevention do not need to be carried out in sequential order and often activities in several of these areas are being conducted simultaneously [4]. This section will highlight key findings from the initial work of the AFEB and the Injury Prevention and Control Working Group and describe how it provided a model for subsequent work in this area.

In determining the scope of the injury problem in step 1 of the public health model, the Injury Prevention and Control Working Group examined available military data on fatalities, disability, hospitalizations, and outpatient care that resulted from injuries [11, 12]. One of their primary objectives was to determine the quality of the available data and to evaluate its utility for injury surveillance. They reported that injuries were the leading cause of fatalities in the military in 1994, accounting for nearly 50% of all deaths [12]. They also reported that rates of medical disability rose for all military services through the 1980s and into the early 1990s. Musculoskeletal injuries and conditions were a leading cause of disability discharge from the military during this time frame, with over 50% of all disability cases reviewed by the Army and Navy being the result of injury-related musculoskeletal and orthopaedic conditions [12]. Musculoskeletal injuries and conditions were also the leading cause of hospitalization in the Army, Navy, and Marine Corps and the second leading cause of hospitalization in the Air Force in 1994 [12]. Combined, injuries and musculoskeletal conditions accounted for 21–48% of all hospitalizations among active duty military personnel across all four branches of service in 1994. High rates of injury-related outpatient visits within the military health system were also reported.

The Injury Prevention and Control Working Group's next task was to identify causes and risk factors associated with injuries in the military (step 2) [12]. To accomplish this task the group reviewed available data on causes of injury routinely collected within the military [12]. These data sources included accident reports and hospital cause of injury codes. They also reviewed the existing evidence on physical training-related injuries from military research centers. Based on the available data, sports-related injuries were the leading cause of hospitalization in both the Army and the Air Force in 1994. Sports- and physical training-related injuries were

also the second leading cause of accidents according to safety data in the Army and Air Force during the same time period. In addition to sports-related injuries, physical training-related musculoskeletal injuries and conditions were also identified as a leading cause of injury in military training populations. Privately owned motor vehicle accidents were also a leading cause of accidents and hospitalizations in the Army and the Air Force.

Once the scope, causes, and risk factors for injury in the military were quantified based on the available data, the Injury Prevention and Control Working Group turned their focus to identifying and evaluating evidence-based injury prevention interventions aligned with the causes and risk factors for injury that they had identified in earlier steps (step 3). The group noted that “To effectively prevent complex public health problems such as injuries, interventions should be tested and evaluated prior to widespread implementation.” [12] To accomplish this they reviewed the available data on injury prevention interventions that had been developed and tested in military training populations. They reported that interventions to reduce running mileage during military training had been shown to substantially reduce lower extremity musculoskeletal injuries without compromising improvements in aerobic fitness. Subsequent studies have confirmed this finding and running frequency, duration, intensity, and volume now follow fairly standardized protocols during initial entry-level military training [14–16]. The group also examined the effectiveness of outside the boot ankle braces to prevent injury during airborne operations (parachuting) [12]. Level I evidence from a randomized controlled trial suggested that this injury prevention intervention produced an 85 % reduction in ankle sprains during airborne training [17], and the brace is now routinely used [12, 17, 18]. Finally, the group found that available evidence did not support the use of shock-absorbent insoles to reduce the incidence of stress fracture during military training [12, 19]. Implementing shock-absorbent insoles at a military training site, without initial testing and evaluation, would have resulted in a significant cost that would have failed to yield any injury prevention benefit. The group suggested that these examples emphasize the importance of studies to evaluate the efficacy of injury prevention intervention efforts prior to wide-scale implementation and adoption [12].

The Injury Prevention and Control Working Group did not implement or evaluate any new injury prevention interventions or programs as part of their initial work; however, they did make important recommendations related to this critical step in the public health model (step 4) [8, 11, 12]. Their work and recommendations related to injury surveillance also provided the foundation for subsequent work in this area [8, 11]. Successful injury prevention interventions require the coordination of various stakeholders (e.g., senior leaders, tactical leaders, policy developers, health-care providers, public health practitioners, etc.) and public health functions (e.g., surveillance, research, implementation science, program evaluation, etc.) [8, 12, 20]. Trials to evaluate the efficacy of interventions and the effectiveness of injury prevention programs in real-world settings are necessary to reduce the risk of musculoskeletal injuries and conditions in the military. Additional strategies to evaluate injury prevention program efficacy and effectiveness are discussed in detail in the following chapters and several models for successful injury prevention practice have been described in the literature [20, 22]. A more thorough discussion

of models for health behavior change is presented later in this chapter. The group recommended that the integration of injury surveillance and research into prevention program development, implementation, and evaluation was critical to overall program success [12]. However, they also noted that demonstrating injury prevention intervention efficacy under controlled research conditions does not ensure program effectiveness when programs are implemented in real-world military training environments [12]. Others have echoed this important aspect of injury prevention program implementation [20, 21].

As a result, the Injury Prevention and Control Working Group emphasized the critical role of ongoing injury surveillance in evaluating the intermediate and long-term effects of injury prevention efforts (step 5). They also provided examples of how injury surveillance data within the military had been used to evaluate injury prevention interventions related to fatalities, motor vehicle accidents, and aviation crashes [12]. They noted that while the data available within the DoD was very valuable for injury surveillance and program evaluation, the process of gathering, collating, and analyzing it was extremely labor intensive and time consuming because disparate data sources lacked connectivity and were widely dispersed between medical, administrative, and personnel databases across the branches of military service [12]. Based on this finding the Injury Prevention and Control Working Group recommended that the DoD should create a comprehensive military medical surveillance system to integrate critical elements of these existing databases [8, 11, 12]. As a result, the Defense Medical Surveillance System (DMSS) and Defense Medical Epidemiological Database were developed [8, 23]. These resources, as well as other surveillance assets [24] within the military, have significantly enhanced injury surveillance and prevention efforts within this high-risk population. They have also made surveillance data available in a much more efficient and timely manner to a broader range of stakeholders.

The results of these initial injury surveillance and prevention efforts utilizing the public health model were described in a special issue of the *American Journal of Preventive Medicine* in 2000 [6, 9]. This compilation of articles did not provide definitive answers on how to mitigate the impact of musculoskeletal injuries and conditions in military populations but they began to frame the critical questions for addressing this important threat to military readiness and provided compelling evidence on the magnitude of the problem [9]. These important questions included identifying which modifiable and non-modifiable risk factors and vulnerabilities place military service members at increased risk for biomechanical injury from acute and repetitive trauma [9]. They also included questions about which injury prevention intervention, or combination of interventions, result in clinically important reductions in injury. Major General James B. Peake stated that “answers to these questions can only come from accurate data collection and large population trials with active command sponsorship [9]. In addition to highlighting these questions, the work of the AFEB and the Injury Prevention and Control Working Group also provided a framework for public health practice related to injury prevention and injury prevention research and program evaluation. Over the next decade, key stakeholders made significant progress toward expanding and extending the initial work of the AFEB and the Injury Prevention and Control Working Group to address

the “hidden epidemic” of injuries in the military; however, this work was complicated by US military involvement in wars on two fronts in the Middle East. Despite this challenge, these stakeholders leveraged the public health model to accomplish this work and they expanded this model to integrate information from other scientific disciplines. These disciplines included health behavior and behavioral health interventions, implementation sciences, and risk management. These collaborations between DoD personnel and civilian researchers have aided in answering some of the important questions noted above and they have led to significant advances in our understanding of the injury problem and the effectiveness of injury prevention interventions within the military.

Contemporary Applications of the Public Health Model for Injury Prevention in the Military

In 2010, a follow-up special issue on injuries in the military was published in the *American Journal of Preventive Medicine* [5, 25, 26]. The supplement was titled “A Public Health Approach to Injury Prevention: The US Military Experience.” The volume provided a refined description of how the public health model for injury prevention had evolved and how it continued to be used to identify injury prevention priorities (Table 14.1). It also aligned the public health approach to injury prevention with the mishap risk management process utilized in the military to facilitate the implementation of injury prevention priorities among line officers, safety officers, and preventive medicine personnel (Table 14.1) [25]. This special issue also provided an update on a decade of progress toward achieving important injury prevention goals and recommendations within the military. Significant progress had been made in developing the infrastructure to support routine surveillance for musculoskeletal injuries and conditions and the ability to use these resources and surveillance data to evaluate injury prevention initiatives had been demonstrated (steps 1, 4, and 5) [4]. Despite these advances, limited progress had been made toward research to identify the causes and risk factors (modifiable and non-modifiable) for injury, or to assess the efficacy of injury prevention interventions (steps 2 and 3). Though Major General James B. Peake noted that effective injury prevention in the military would be dependent on accurate data collection (surveillance) and large population trials with active command sponsorship in 2000 [9], the latter had yet to be realized. Jones et al. [4] noted that there was no dedicated injury prevention research objective or program for the military at the time the issue was published. Though limited progress was made in the area of research, additional advances were made in expanding the public health approach to injury prevention in the military. In addition to leveraging and applying the public health approach to injury prevention outlined in Table 14.1, key leaders recognized the need to develop and implement a systematic evidence-based approach for injury prevention in the military [4].

Table 14.1 Steps in applying the public health approach to prevent musculoskeletal injuries and conditions in the US military and alignment with the US Army mishap risk management process. (Adapted from [4, 25])

Public health process for injury prevention	Description	US Army mishap risk management
<i>Step 1:</i> Quantify the burden of injuries through surveillance	Routine injury surveillance quantifies the frequency, rates, and trends in musculoskeletal injuries and conditions at the population level. These data are used to identify emerging and ongoing areas of concern and can be used to help set injury prevention priorities	<i>Step 1:</i> Identify and assess hazards
<i>Step 2:</i> Identify the cause and risk factors	Information from observational research and public health practice is used to identify the causes and risk factors for musculoskeletal injuries and conditions. The focus should be on identifying modifiable and non-modifiable risk factors as this information can be used to target injury prevention interventions and groups at the highest risk for injury, respectively	<i>Step 2:</i> Determine risk (loss severity and probability)
<i>Step 3:</i> Research on injury prevention interventions	Injury prevention interventions targeting the modifiable risk factors in high-risk groups are developed and implemented. Randomized controlled trials and non-randomized studies are conducted to evaluate the efficacy of these injury prevention interventions under controlled conditions	<i>Step 3:</i> Develop risk reduction controls
<i>Step 4:</i> Injury prevention program and policy implementation	Key stakeholders including senior leaders, tactical leaders, policy makers, health-care providers, and public health practitioners, work together to develop and implement evidence-based injury prevention programs and policies based on the available evidence identified in steps 1–3	<i>Step 4:</i> Make risk acceptance decisions
<i>Step 5:</i> Ongoing program and policy evaluation and monitoring	Ongoing injury surveillance and program evaluation studies are conducted to examine the effectiveness of injury prevention programs and policies during and following implementation	<i>Step 5:</i> Implement controls, supervise implementation, and evaluate outcomes

Evidence-based decision-making has garnered significant support in public health practice and policy in recent years and has contributed to the development of research priorities. Contemporary injury prevention practice and policy should be guided by a systematic evaluation of the best evidence available. A systematic review of the available evidence can also aid in identifying knowledge gaps that need to be addressed through research to advance injury prevention priorities. Jones et al. [4] recently described a systematic process for evidence-based decision-making and injury prevention in the military. The evidence-based decision-making process described by Jones et al. [4] focused on six steps including: (1) identifying the biggest or most severe injury problems; (2) systematically searching and reviewing the existing scientific evidence on effective injury prevention interventions based on the injury prevention priorities established in step 1; (3) objectively evaluating the quality of the individual research studies identified in step 2 using established review criteria; (4) making injury prevention recommendations based on the overall strength and consistency of the evidence; (5) prioritizing injury prevention interventions based on available resources, the magnitude and severity of the problem, the efficacy and effectiveness of interventions, and feasibility; and (6) identification of research gaps and priorities. Important aspects of the evidence-based decision-making process for injury prevention outlined above include evaluating the quality and findings of individual studies, and synthesizing the results across studies, to make evidence-based recommendations grounded in the strength and consistency of the available evidence. To address the latter, the authors provided criteria for making recommendations on injury prevention strategies based on the synthesis of effects across studies [4]. They also provided criteria and tools for establishing injury prevention practice and research priorities in the military.

Canham-Chervak et al. [27] applied this systematic approach for prioritizing injury prevention activities in a separate paper in the same special issue of the *American Journal of Preventive Medicine*. Their stated objectives were to (1) refine previous prioritization efforts by systematically utilizing input from experts with public health training and experience evaluating epidemiological data and the scientific literature, and (2) apply defined criteria to identify top DoD injury causes most amenable to implementation of injury prevention programs and policies [27]. Musculoskeletal injuries and conditions due to physical training were identified as the top priority for injury prevention, followed by military parachuting injuries, injuries due to privately owned motor vehicle crashes, and sports-related injuries. These and other leading causes of injury in the military were systematically evaluated using the following criteria: (1) importance of the problem to health and military readiness, (2) preventability of the problem, (3) feasibility of injury prevention or policy interventions, (4) timeliness of implementation and results, and (5) ability to evaluate programs or policy outcomes. Though the authors applied a systematic approach to identifying injury prevention priorities, they noted some limitations associated with the process and areas for improvement. A primary limitation was that the process relied on cause of injury coding from hospitalization data and did not include cause of injury for outpatient encounters [27]. This is an important limitation because the majority of musculoskeletal injuries and conditions are treated in outpatient clinics.

Despite the significant advances in injury surveillance within the military, accurate cause of injury coding for outpatient encounters remains problematic in the military health system. A key area for improving the systematic process for establishing injury prevention priorities focused on involving the raters earlier in the process so that they could have input into the final criteria and methods used; however, the authors noted the need to balance scientific rigor with the need for a timely response to pressing public health issues might preclude this in public health practice [27].

Ruscio et al. [28] applied a similar systematic process to identify injury prevention priorities based on injury type, cause of injury, and morbidity measured by the number of limited duty days associated with injury. The authors reviewed hospitalization data and data for outpatient encounters documented in the DMSS for 2004. They identified the leading injury types by body region for acute injuries and injury-related musculoskeletal conditions. The authors also estimated the number of limited duty days for each diagnosis by body region. Limited duty days for the top five acute injuries resulting in outpatient encounters were (1) lower extremity fractures which resulted in 7928 person-years of limited duty (20%), (2) upper extremity fractures which resulted in 6450 person-years of limited duty (17%), (3) lower extremity sprains and strains which resulted in 5144 days of limited duty (14%), (4) lower extremity joint dislocations and cartilage tears resulting in 4166 person-years of limited duty (11%), and (5) sprains and strains to the spine and back which resulted in 3293 person-years of limited duty (9%). Limited duty days for the top five injury-related musculoskeletal conditions requiring outpatient care were (1) lower extremity overuse injuries (pain, inflammation, and stress fractures) which resulted in 10,420 person-years of limited duty (34.5%), (2) overuse injuries to the torso (pain, inflammation, and stress fractures) which resulted in 5933 person-years of limited duty (19.6%), (3) upper extremity overuse injuries (pain, inflammation, and stress fractures) which resulted in 3600 person-years of limited duty (11.9%), (4) unspecified overuse injuries (pain, inflammation, and stress fractures) which resulted in 2737 limited duty days (9%), and (5) lower extremity sprains, strains, and ruptures which resulted in 1896 person-years of limited duty (6.3%). These data systematically provide a measure of the impact of musculoskeletal injuries in the military population, specifically in terms of work-related disability associated with the leading diagnoses for musculoskeletal injuries and conditions among service members. In addition to quantifying the burden of these injuries in terms of military readiness, they also provide objective data for developing injury prevention priorities.

The causes of the top acute injury diagnoses were also examined [28]. Transportation-related accidents (e.g., motor vehicle or vessel) were the leading cause of upper and lower extremity fractures and sprains and strains to the back. Sports and physical training were the leading cause of lower extremity sprains, strains, and dislocations. Sports and physical training was also among the top three causes for all of the other leading diagnosis categories examined. Using the systematic process described above by Jones et al. [4], service-specific injury prevention program and policy priorities were established based on these data (Table 14.2) [28]. Sports and physical training-related musculoskeletal injuries were identified as a leading

Table 14.2 Injury prevention program and policy priorities by service. (Adapted from [28])

Cause of injury	Air Force		Army ^a		Marine Corps		Navy	
	Average score (max =40)	Rank	Average score (max =40)	Rank	Average score (max =40)	Rank	Average score (max =40)	Rank
Sports and physical training (PT) ^a	29.2	2	PT: 34.0 SPT: 28.4	PT: 1 SPT: 4	28.5	2	27.0	2
Privately owned vehicle (POV) accident	32.0	1	27.2	5	24.3	4	26.0	3
Falls	26.3	3	30.6	3	28.0	3	28.0	1
Twist/turn (w/o fall)	21.8	6	24.6	8	20.7	7	19.3	6
Nontraffic (POV and MIL)	20.3	7	19.4	10	17.8	8	19.0	7
Parachuting	20.2	8	31.8	2	NR	NR	16.0	8
Guns and explosives	24.2	4	26.2	6	36.3	1	22.8	4
Military vehicle accidents	23.0	5	26.2	6	23.5	5	NR	NR
Tools and machines	NR	NR	21.0	9	21.5	6	21.8	5

SPT sports, *PT* physical training, *POV* privately owned vehicle, *MIL* military, *NR* not rated

^a The Army ranked sports separate from physical training; the other services provided a combined score for sports and physical training

priority for injury prevention and policy prioritization across the services. Based on these data, the authors made recommendations for injury prevention interventions [34] that included (1) evaluating environmental, behavioral, directive, or regulatory interventions to prevent injuries related specifically to sports and physical training; (2) endorse evidence-based recommendations from systematic reviews for sports and physical training-related injury prevention, including but not limited to parachute ankle braces, mouth guards, breakaway bases for softball, and ankle braces for sports with high risk for ankle injury such as soccer and basketball; (3) provide resources and policy priority to the biggest, most preventable problems identified which include, but are not limited to, sports and military physical training, falls, and privately owned vehicle accidents; and (4) endorse the Joint Services Physical Training Injury Prevention Working Group's recommendations for the prevention of physical training-related injuries [29].

Ruscio et al. [28] also made several recommendations for injury prevention research priorities and noted that addressing these strategic research priorities could greatly enhance prevention efforts across the DoD. The top research priorities identified included (1) epidemiologic research on falls and physical training in operational units; (2) enhanced methods to obtain injury data for sports, exercise, and recreation-related musculoskeletal injuries; (3) assessment of the impact of leading injuries on disability and medical separation; and (4) evaluation of current methodologies and results to ensure application in the deployed environment. The latter is particularly important as non-battle injuries are a leading cause of medical evacuation from theater during military deployments, and sports and physical training are a leading cause of these injuries [30]. See Chap. 3 in this book for a detailed review on the burden of non-battle musculoskeletal injuries and conditions during deployment.

The application of the public health model for injury prevention within the military continues to evolve. Combined with a systematic approach and evidence-based decision-making process, injury prevention efforts within the military continue to gain traction and increased attention from military leaders and policy makers. However, notable gaps, particularly in injury prevention research, remain. The lack of a dedicated injury prevention research objective or program for the military remains a significant barrier to advancing injury prevention efforts. Despite significant increases in research funding through the Congressionally Directed Medical Research Program over the past decade, very little of this funding has been allocated to align with important injury prevention goals or the injury prevention intervention and research priorities identified above.

Integrating Health Behavior into Injury Prevention Interventions: Applications for the Public Health Model

Public health research has consistently demonstrated that passive injury prevention interventions that can be engineered into the environment yield better results than active interventions where individuals or organizations must consciously modify

their behavior. Unfortunately, the efficacy and effectiveness of many injury prevention interventions is dependent on health-related behavior at multiple levels of the organization in order to initiate and sustain clinically important behavior change [31]. Despite the inherent structure within the military, this is also true for injury prevention efforts in military populations. As a result, it is critical for injury prevention research and practice to integrate theories of health behavior change, and these theories are particularly important when designing and implementing injury prevention interventions [32]. Implementation science is another emerging field in public health that can inform injury prevention practice and research. According to the National Institutes of Health (NIH) Fogarty International Center, implementation science is the study of methods to promote the integration of research findings and evidence into public health policy and practice [33]. The goal of implementation science is to understand the behavior of patients, health-care professionals, and other stakeholders as a key variable in the sustainable uptake, adoption, and implementation of evidence-based interventions in real-world settings [33]. Despite the advances that have been made toward injury prevention in the military, efforts to integrate theories of health behavior change or implementation science into injury prevention research and practice are limited [20].

Several conceptual frameworks and models have been developed to aid in designing, implementing, and evaluating evidence-based health promotion interventions [32]. These models incorporate health behavior theories and are directly applicable to injury prevention interventions. Two of the most comprehensive models that have been developed are the PRECEDE/PROCEED planning model [22] and the Diffusion of Innovations model [34]. The Reach Effectiveness Adoption Implementation Maintenance (RE-AIM) framework also provides a theory-based model that is applicable to injury prevention interventions [32]. All of these models are directly aligned with the goals of implementation science [33]. This section will provide a brief overview of how health behavior theories and the emerging field of implementation science can be used to improve injury prevention intervention effectiveness and outcomes, particularly in the military setting.

Intervention planning and implementation is an iterative process and the PRECEDE/PROCEED model is well suited for planning and evaluating injury prevention interventions that rely on changes in health behavior. The PRECEDE/PROCEED framework is an evidence-based model that has been used effectively for developing and implementing comprehensive behavioral interventions to reduce injuries and injury risk [22]. The main purpose of the framework is to provide a structure for applying health behavior theories and concepts systematically during the planning, implementation, and evaluation of behavior change interventions. The PRECEDE/PROCEED framework also provides a model for integrating key theoretical constructs into the planning and evaluation of behavioral interventions [22]. According to Gielen et al. [22], the PRECEDE/PROCEED framework can be effectively used to build comprehensive injury prevention programs that rely on behavior change through “intervention matching, mapping, pooling, and patching.” There are four steps within the PRECEDE portion of the model and these steps primarily align with the planning and development of the intervention. These

phases include (1) social assessment, participatory planning, and situational analysis of the intervention context; (2) epidemiological, behavioral, and environmental assessments; (3) educational and ecological assessment; and (4) administrative and policy assessment and intervention alignment [22]. Gielen et al. [22] provide guidelines and recommendations for how appropriate health behavior theories can be integrated into each of these for planning phases. For example, social cognitive theory might be applied to assess and address potential personal, behavioral, and environmental determinants related to the success of the behavioral change intervention.

Four phases also comprise the PROCEDE portion of the model which is primarily aligned with the implementation and evaluation of the intervention. These phases include (5) implementation, (6) process evaluation, (7) impact evaluation, and (8) outcome evaluation [22]. Process evaluation focuses on the extent to which the program is implemented according to plans. Factors that are related to process evaluation include intervention fidelity and adherence/compliance. Intervention fidelity is the degree to which interventions are implemented as intended by program planners [35]. Intervention adherence or compliance is the baseline measure of fidelity. For example, intervention adherence is focused on whether an individual performed the intervention (e.g., exercises to improve neuromuscular control) when they were supposed to, while intervention fidelity more broadly defined would also be concerned with whether the intervention exercises were performed correctly as prescribed. Impact evaluation is typically focused on assessing changes in behavioral and environmental factors, as well as predisposing, reinforcing, and enabling factors that influence the outcomes of the behavioral intervention [32]. Outcome evaluation focuses on whether important health and quality of life measures are altered due to the intervention (e.g., decrease in injury rates, decrease in attrition, etc.). Overall, the PRECEDE/PROCEDE framework can be useful in planning, implementing, and evaluating injury prevention interventions that rely on behavior change at multiple levels of an organization and this model has direct applicability to injury prevention efforts within military settings. Gielen et al. [32] provide a detailed description of the PRECEDE/PROCEDE framework and examples of its use for intervention planning and evaluation for readers who are interested in more information about this model.

The Diffusion of Innovations model is focused on the factors that facilitate and/or inhibit evidence-based interventions from being adopted and translated to injury prevention practice [36]. A detailed description of the model is provided by Oldenburg and Glanz [34], but we will provide an overview here. In the model, diffusion is defined as the process by which the spread or adoption of an innovation (e.g., injury prevention intervention) over time occurs across key stakeholders within a social system [34]. We will use innovation and intervention interchangeably in this section. The Diffusion of Innovations model relies on key concepts in two broad categories that include (1) foundational concepts and stages of diffusion, and (2) characteristics of interventions that determine diffusion [34]. The primary stages of diffusion include intervention development, adoption, implementation, maintenance, sustainability, and institutionalization [34]. Characteristics of interventions

that influence diffusion focus on key questions and attributes. These questions include: (1) Is the intervention better than what was there before? (Attribute: relative advantage); (2) Does the intervention fit with the intended audience and within the intended intervention context? (Attribute: compatibility); (3) Is the intervention easy to implement? (Attribute: complexity); (4) Can the intervention be tested before making a decision to adopt? (Attribute: trialability); and (5) Are the results of the intervention readily apparent, easily measureable, and clinically important? (Attribute: observability) [34]. Overall, the Diffusion of Innovations model has been widely used to translate evidence-based interventions that require behavioral change into public health practice. While all models have noted limitations, aspects of the Diffusion of Innovations model have direct applicability to injury prevention efforts within the military which may aid in improving intervention diffusion and dissemination.

Other theoretical models and conceptual frameworks have also been described that could inform injury prevention intervention development, implementation, and evaluation [20, 21, 32, 37]. Some of these models may have direct applicability to injuries in young and physically active populations comparable to the military. The RE-AIM framework outlines important dimensions and critical questions that should be addressed when evaluating injury prevention intervention programs that rely on behavior change [32]. Chapter 16 in this book provides a detailed description of the RE-AIM framework and how it might be used to overcome barriers to effectively implementing evidence-based injury prevention interventions in the military. Additional information about the RE-AIM framework is also available [32, 38].

Finch and colleagues [21, 38-42,] have played a leading role in integrating implementation science into injury prevention interventions in active populations. Specifically, the Translating Research into Injury Prevention Practice (TRIIPP) model described by Finch [21] focused on the importance of intervention effectiveness in addition to efficacy and raised important questions about program development and implementation that might affect translation of research results to practice. More recently, Padua et al. described seven steps that are critical to intervention development and implementation specifically within the context of a military training environment [20]. These steps include (1) establishing administrative and leadership support, (2) developing an interdisciplinary team that includes key stakeholders, (3) identifying potential logistical barriers to effective implementation and identifying solutions to address these concerns, (4) developing an evidence-based injury prevention program that is aligned with stakeholder objectives and contextual constraints, (5) training intervention personnel, (6) evaluating intervention fidelity through process evaluation, and (7) developing an exit and transition strategy that promotes sustainability and institutionalization. Overall, there are several established theoretical models that could be readily applied to improve injury prevention implementation, sustainability, and institutionalization within the military. These models directly align with the public health approach and systematic evidence-based decision-making processes that have been applied to tackle the musculoskeletal injury challenge within the military population.

Summary

In combination with a systematic evidence-based decision-making process, the public health model for injury prevention can significantly improve injury prevention practice, policy, and research within the military. In addition, this framework can be used to set important injury prevention priorities and to make decisions about resource allocations that are aligned with these priorities. Because the success of many injury prevention interventions within the military relies on behavior change at the individual or organizational levels, established theories of health behavior should be integrated into intervention planning, implementation, and evaluation. Some of the more comprehensive models available include the PROCEDE/PRECEDE model, the Diffusion of Innovations model, and the RE-AIM framework. While all of these models have strengths and weaknesses, they provide a conceptual framework grounded in theory that is likely to improve injury prevention outcomes. The emerging field of implementation science will also play a critical role in the future success of injury prevention interventions within the military.

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References

1. Withers BG, Craig SC. The historical impact of preventive medicine in war. In: Kelley PW, editor. Textbook of military medicine: military preventive medicine, mobilization, and deployment. Vol. 1. Washington, D.C.: Office of the Surgeon General at TMM Publications; 2003, pp. 21–57.
2. Withers BG, Erickson RL, Petrucci BP, Hanson RK, Kadlec RP. Preventing disease and non-battle injury in deployed units. *Mil Med*. 1994;159(1):39–43.
3. Llewellyn CH. Preventive medicine and command authority: Leviticus to Schwarzkopf. Textbook of military medicine: military preventive medicine, mobilization, and deployment. Vol. 1. Washington, D.C.: Office of the Surgeon General at TMM Publications; 2003, p. 3–19.
4. Jones BH, Canham-Chervak M, Sleet DA. An evidence-based public health approach to injury priorities and prevention recommendations for the U.S. Military. *Am J Prev Med*. 2010;38(1 Suppl):1–10.
5. Sleet DA, Baldwin G. It wouldn't hurt to create a safer military. *Am J Prev Med*. 2010;38(1 Suppl):218–21.
6. Sleet DA, Jones BH, Amoroso PJ. Military injuries and public health. An introduction. *Am J Prev Med*. 2000;18(3 Suppl):1–3.
7. US Army Public Health Command. US Army public health command history. US Army public health command. http://phc.amedd.army.mil/Documents/CIS002_USAPHC_History_ro.pdf. Accessed 11 March 2015.
8. Jones BH, Hansen BC. An armed forces epidemiological board evaluation of injuries in the military. *Am J Prev Med*. 2000;18(3 Suppl):14–25.

9. Peake JB. Reflections on injuries in the military: the hidden epidemic. *Am J Prev Med.* 2000;18(3 Suppl):4–5.
10. Hauret KG, Jones BH, Bullock SH, Canham-Chervak M, Canada S. Musculoskeletal injuries description of an under-recognized injury problem among military personnel. *Am J Prev Med.* 2010;38(1 Suppl):61–70.
11. Jones BH, Hansen BC. Injuries in the military: a hidden epidemic. Aberdeen proving ground, MD: department of defense: U.S. Army center for health promotion and preventive medicine; 1996:5-1 to 5–15.
12. Jones BH, Perrotta DM, Canham-Chervak ML, Nee MA, Brundage JF. Injuries in the military: a review and commentary focused on prevention. *Am J Prev Med.* 2000;18(3 Suppl):71–84.
13. US Army Public Health Command. US Army public health command. US Army public health command. http://phc.amedd.Army.mil/Documents/CIS001_USAPHC_ro.pdf. Accessed 11 March 2015.
14. Knapik J, Darakjy S, Scott SJ, et al. Evaluation of a standardized physical training program for basic combat training. *J Strength Cond Res.* 2005;19(2):246–53.
15. Knapik JJ, Scott SJ, Sharp MA, et al. The basis for prescribed ability group run speeds and distances in U.S. Army basic combat training. *Mil Med.* 2006;171(7):669–77.
16. Knapik JJ, Rieger W, Palkoska F, Van Camp S, Darakjy S. United States Army physical readiness training: rationale and evaluation of the physical training doctrine. *J Strength Cond Res.* 2009;23(4):1353–62.
17. Amoroso PJ, Ryan JB, Bickley B, Leitschuh P, Taylor DC, Jones BH. Braced for impact: reducing military paratroopers' ankle sprains using outside-the-boot braces. *J Trauma.* 1998;45(3):575–80.
18. Knapik JJ, Spiess A, Swedler DI, Grier TL, Darakjy SS, Jones BH. Systematic review of the parachute ankle brace: injury risk reduction and cost effectiveness. *Am J Prev Med.* 2010;38(1 Suppl):182–8.
19. Gardner LI, Jr, Dziados JE, Jones BH, et al. Prevention of lower extremity stress fractures: a controlled trial of a shock absorbent insole. *Am J Public Health.* 1988;78(12):1563–7.
20. Padua DA, Frank B, Donaldson A, et al. Seven steps for developing and implementing a preventive training program: lessons learned from JUMP-ACL and beyond. *Clin Sports Med.* 2014;33(4):615–32.
21. Finch C. A new framework for research leading to sports injury prevention. *J Sci Med Sport.* 2006;9(1–2):3–9. (Discussion 10)
22. Gielen AC, McDonald EM, Gary TL, Bone LR. Using the PRECEDE-PROCEED model to apply health behavior theories. In: Glanz K, Rimer BK, Viswanath K, editors. *Health behavior and health education: theory, research, and practice.* 4th ed. San Francisco: Jossey-Bass; 2008, p. 405–29.
23. Rubertone MV, Brundage JF. The defense medical surveillance system and the department of defense serum repository: glimpses of the future of public health surveillance. *Am J Public Health.* 2002;92(12):1900–4.
24. Hauret KG, Jones BH, Canham-Chervak M, Bullock SH, Canada S, Knapik JJ. Frequencies and characteristics of medical evacuations of soldiers by air (with emphasis on non-battle injuries), Operations Enduring Freedom/Iraqi Freedom (OEF/OIF). *Med Surveill Mon Rep (MSMR).* 2004;10(3):8–12.
25. Gunlicks JB, Patton JT, Miller SF, Atkins MG. Public health and risk management a hybridized approach to military injury prevention. *Am J Prev Med.* 2010;38(1 Suppl):214–6.
26. Schoomaker LE. The U.S. Army medical department commitment to injury reduction. *Am J Prev Med.* 2010;38(1 Suppl):S217.
27. Canham-Chervak M, Hooper TI, Brennan FH, Jr, et al. A systematic process to prioritize prevention activities sustaining progress toward the reduction of military injuries. *Am J Prev Med.* 2010;38(1 Suppl):11–8.
28. Ruscio BA, Jones BH, Bullock SH, et al. A process to identify military injury prevention priorities based on injury type and limited duty days. *Am J Prev Med.* 2010;38(1 Suppl):19–33.

29. Bullock SH, Jones BH, Gilchrist J, Marshall SW. Prevention of physical training-related injuries recommendations for the military and other active populations based on expedited systematic reviews. *Am J Prev Med.* 2010;38(1 Suppl):156–81.
30. Hauret KG, Taylor BJ, Clemmons NS, Block SR, Jones BH. Frequency and causes of non-battle injuries air evacuated from operations Iraqi freedom and enduring freedom, U.S. Army, 2001–2006. *Am J Prev Med.* 2010;38(1 Suppl):94–107.
31. Glanz K, Rimer BK, Viswanath K. The scope of health behavior and health education. In: Glanz K, Rimer BK, Viswanath K, ed. *Health behavior and health education: theory, research, and practice.* 4th ed. San Francisco: Jossey-Bass; 2008, p. 3–22.
32. Glasgow RE, Linnan LA. Evaluation of theory-based interventions. In: Glanz K, Rimer BK, Viswanath K, editors. *Health behavior and health education: theory, research, and practice.* 4th ed. San Francisco: Jossey-Bass; 2008, p. 487–508.
33. National Institutes of Health Fogarty International Center. Implementation science information and resources National Institutes of Health Fogarty International Center. <http://www.fic.nih.gov/researchtopics/pages/implementation-science.aspx>. Accessed 14 April 2015.
34. Oldenburg B, Glanz K. Diffusion of innovations. In: Glanz K, Rimer BK, Viswanath K, editors. *Health behavior and health education: theory, research, and practice.* 4th ed. San Francisco: Jossey-Bass; 2008, p. 313–33.
35. Carroll C, Patterson M, Wood S, Booth A, Rick J, Balain S. A conceptual framework for implementation fidelity. *Implement Sci.* 2007;2:40.
36. Poulos RG, Donaldson A. Improving the diffusion of safety initiatives in community sport. *J Sci Med Sport.* 2014;18(2):139–44.
37. van Mechelen W, Hlobil H, Kemper HC. Incidence, severity, aetiology and prevention of sports injuries. A review of concepts. *Sports Med.* 1992;14(2):82–99.
38. O'Brien J, Finch CF. The implementation of musculoskeletal injury-prevention exercise programmes in team ball sports: a systematic review employing the RE-AIM framework. *Sports Med.* 2014;44(9):1305–18.
39. Donaldson A, Finch CF. Applying implementation science to sports injury prevention. *Br J Sports Med.* 2013;47(8):473–5.
40. Donaldson A, Cook J, Gabbe B, Lloyd DG, Young W, Finch CF. Bridging the gap between content and context: establishing expert consensus on the content of an exercise training program to prevent lower-limb injuries. *Clin J Sport Med.* 2015;25(3):221–229.
41. O'Brien J, Finch CF. A systematic review of core implementation components in team ball sport injury prevention trials. *Inj Prev.* 2014;20(5):357–62.
42. Verhagen E, Voogt N, Bruinsma A, Finch CF. A knowledge transfer scheme to bridge the gap between science and practice: an integration of existing research frameworks into a tool for practice. *Br J Sports Med.* 2013;48(8):698–701.

Chapter 15

Successful Injury Prevention Interventions

Sarah J. de la Motte and Robert Oh

Introduction

Musculoskeletal injury (MSK-I) in the military contributes to the largest number of lost duty days and financial burden more than any other disease or condition [1]. Capitalizing on the closed medical system and structured community, many successful interventions have been implemented over the years to address this problem in military communities. These interventions designed using the public health approach (Chap. 13) have proven to be particularly effective over the years. By systematically addressing the issue, the number of MSK-Is in various types of military settings has decreased in specific military subpopulations. This chapter outlines the evolution of injury prevention successes and discusses recommended steps for future MSK-I prevention interventions in the military.

Successful Injury Prevention

Successful injury prevention has typically followed a four-step model, taking interventions from research to practical application (Fig. 15.1). In the military, the ability of multiple organizational bodies, including training, leadership, and medical systems, to combine efforts to prioritize prevention has opened doors for effective programs unlike many other populations. There has been consistent and substantial evolution of evidence-based injury prevention interventions in the military through-

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267

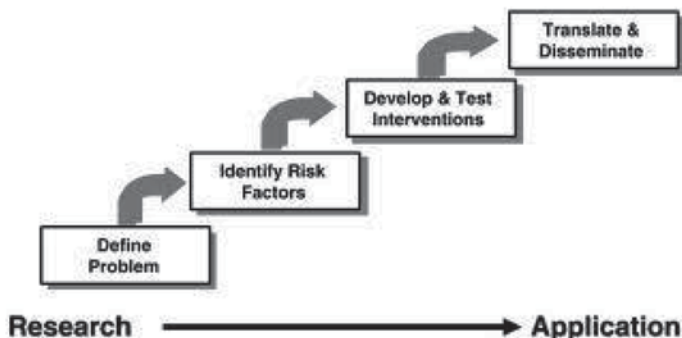


Fig. 15.1 Traditional four-step model of injury prevention

out the years. The existence of multiple epidemiologic databases housing relevant information on service members has allowed for the development of data-driven approaches for injury prevention. By accurately describing the extent of the problem (Step 1) and identifying risk factors, etiology, and injury mechanism (Step 2), successful intervention development (Step 3) has focused on six main principles: (1) program/policy consistent with mission, (2) important, (3) preventable, (4) feasible, (5) timely, and (6) evaluative [2]. Under this quantitative framework, specific MSK-I prevention interventions in the military have established effective and sustainable strategies and systems to address the problem. By focusing on these six main principles, numerous effective injury prevention initiatives have been successfully implemented and maintained. First, unless it can be shown that a program or policy is consistent with the organization's mission (in the military case, operational readiness), it is not worth developing. Next, the importance of the issue to be addressed (MSK-I) and its preventative nature (modifiable risk factors) must be supported by sufficient evidence to justify the need and potential effectiveness for the program and/or policy. Feasibility and timeliness of injury prevention interventions are key to implementation and political will to facilitate program maintenance. Finally, it is essential to ensure that programs and policy effectiveness can be successfully evaluated, and that the benefits of such policies (injury reduction and decreased financial burden) outweigh the costs (financial and lost duty days), if injury prevention interventions are to be successful.

Essential Elements for Military Injury Prevention Program Success

In 2004, the Military Training Task Force of the Defense Safety Oversight Council chartered a Joint Services Physical Training Injury Prevention Working Group to establish the evidence base, prioritize, and recommend proven injury prevention

programs to the Secretary of Defense [3]. Additionally, this working group was tasked with substantiating the need for further research and evaluation on interventions and programs likely to reduce physical training-related injuries—namely, MSK-Is. The results of an expedited systematic review determined four elements essential to injury prevention success: education, surveillance, leadership support, and adequate resources for research and program evaluation.

Education

Successful injury prevention should involve informing and educating those involved in all aspects of military training. Injury prevention programs that involve education are more likely to increase adherence and show success [4]. Education includes dissemination of information regarding the proven strategies for the prevention of injury, educating those who deliver training programs, and those who are responsible for training troops at all levels. Perhaps most importantly, effective education is a crucial component for obtaining military commanders' support for evidence-based injury prevention interventions that are aligned with their responsibility to protect service members [3].

Surveillance

Without adequate and widespread surveillance, it is difficult to appreciate the magnitude of the MSK-I problem in the military, which presents challenges for deciding where to intervene. Surveillance reporting on specific injuries (e.g., stress fracture) and training events (e.g., pugil sticks) provides the foundation for identifying problem areas and informing improvement strategies. Through the synthesis of information about injury rates and training by unit level, training cycle, fiscal or calendar year, and goals for improvement, targeted interventions can be thoroughly evaluated and recommendations made in an evidenced-based manner.

Numerous Department of Defense (DoD)-wide surveillance systems exist, including the Defense Medical Surveillance System (DMSS) administered by the Armed Forces Health Surveillance Center (AFHSC), and the Military Health System Data Repository (MDR). However, more importantly, most training units carefully track their own outcomes, including number of dropped trainees, unit fitness test performance, and in coordination with medical staff, in-house injury rates. Routine surveillance of unit-level injuries and fitness can and should be used as an indicator of physical training program success or failure and is an invaluable tool for garnering leadership support. Local injury surveillance infrastructure and data are also critical for providing timely and actionable data to military leaders at the strategic, operational, and tactical levels.

Leadership Support

Leadership focus at all levels of the organization, from the highest-level military commanders to the squad leader, has the greatest influence on MSK-I rates and whether an injury prevention intervention will be successful or not. Simply understanding the current state of specific injuries, their contributing causes, setting goals to improve outcomes, and monitoring success through surveillance can be an effective way to gain leadership support for injury prevention initiatives. High injury rates indicate a need to modify existing training programs, with command-level decisions having broad-reaching impacts. Regular reporting of injury data through the chain of command may have the effect of encouraging greater command responsibility for unit performance, including MSK-I. However, most importantly, recent work shows that successful short-term prevention program implementation and ultimate long-term sustainability are only possible with complete leadership buy-in and support [5]. Key to obtaining this support is aligning the mutual goal of injury prevention along with the overall mission of military leaders (i.e., operational readiness). Both buy-in and support from leaders and key stakeholders are paramount to garnering commitment for successful implementation and ultimate sustainability of injury prevention initiatives [5].

Research and Program Evaluation

While there have been many successful injury prevention programs reported, there are many more that lack sufficient evidence for implementation. There is a great need for branch or service-level research and program evaluation of multiple types of injury prevention strategies in military populations. More importantly, there is a great need for the willingness and desire to devote resources to implement, disseminate, track, and evaluate new strategies for injury prevention. The following section describes the latest research and program evaluation for successful military injury prevention strategies.

Successful Injury Prevention Strategies

While there have been numerous interventions, three broad categories have shown the most success: (1) preventing overtraining; (2) ankle bracing; and (3) performing multiaxial, neuromuscular, proprioceptive, and agility training.

Risk Factor Identification

Training-related risk factors for MSK-I have been clearly identified [6–8]. Risk factors have traditionally been categorized into intrinsic and extrinsic risk factors. Intrinsic risk factors are factors inherent in the individual, while extrinsic risk factors are environmental factors that interfere with the individual. Intrinsic risk factors can be further grouped into demographic factors (age, gender, race, tobacco use, history of previous MSK-I), anatomical factors (high arches and genu valgus), and physical fitness factors (low aerobic fitness, endurance, and strength; see Table 15.1). Extrinsic risk factors vary with the training environment. High running mileage, certain training companies, older running shoes, and the summer season have been identified as risk factors for overuse injury in Basic Combat Training (BCT) [9]. Injury prevention strategies for training-related injuries attempt to modify both intrinsic and extrinsic risk factors.

However, a recent paradigm shift in the conceptualization of risk factors has begun to focus on whether risk factors for MSK-I are “modifiable” or “non-modifiable.” Intrinsic and extrinsic risk factors, which may be interrelated and influence each other, whereas modifiable or non-modifiable risk factors allow for straightforward identification on specific risk factors that are amenable to change (i.e., modifiable) [10, 11]. In order to prevent MSK-I, it is critical to identify and focus on the modifiable risk factors associated with injury as these factors are likely amenable to intervention. As a result, classifying risk factors by whether they are modifiable or non-modifiable is much more relevant from a clinical and injury prevention perspective. Non-modifiable risk factors are important to help identify which populations are at greatest risk for injury so that prevention resources can be justifiably directed to these populations. However, as many intrinsic and extrinsic risk factors are in essence modifiable, they hold the most promise as targets for truly successful injury prevention interventions. Table 15.1 describes identified risk factors for training-related MSK-I across various categories and whether they are considered modifiable (M) or non-modifiable (N).

Table 15.1 Risk factors for training-related injury

Demographic factors	Anatomical factors	Physical fitness factors
Age > 24 years (N)	Genu valgus (N)	Low levels of physical activity before training (M)
Caucasian race (N)	Q-angle > 15° (N)	Low aerobic fitness (M)
Female gender (N)	Decrease ankle dorsiflexion (M)	Extremes of flexibility (M)
Previous musculoskeletal injury (N)	Rearfoot hyperpronation (M)	Low muscular strength and endurance (M)
Tobacco use (M)	Extremes of arches (pes cavus/pes planus) (M)	Extremes of BMI and body composition (M)

N non-modifiable risk factor for injury, *M* modifiable risk factor for injury,
BMI body mass index

Preventing Overtraining

Training Modification—Decreasing Running Mileage

Overtraining in the military has been established as a primary cause for MSK-I in military training populations. Overtraining is defined as “the physiology of musculoskeletal overuse due to exercise or physical training” [3]. In addition to overuse injuries, overtraining can lead to a decrement in performance, fatigue, and immune dysfunction. It is estimated that up to 80% of the lower extremity injuries suffered in basic training are of the overuse type and are likely attributed to low levels of recruits’ baseline level of fitness [3]. While physical training is an essential part of military training and practice, the overwhelming increase of unfit individuals entering military service and the associated alarming increase in stress fracture incidence in basic training (see Chap. 5 on initial entry training (IET) injuries) has led to the establishment of several graduated and interval training interventions designed to increase baseline levels of fitness while preventing overtraining and MSK-I [12–15].

Evidence from survey and epidemiologic research has demonstrated that high running volume is strongly associated with overtraining and lower extremity injury. Several studies have established that altering running volume can prevent MSK-I in training troops without negative effects on fitness. A study by Shaffer et al. [16] on Marine Corp trainees found that decreasing the running mileage in basic training by 40%, *decreased stress fracture incidence by more than 50%*, and most importantly, all without affecting physical fitness test performance [17] (see Table 15.2). The dramatic reduction of stress fracture rates from simply reducing running mileage was estimated to have saved \$4.5 million in direct medical care costs and nearly 15,000 training days per year [16].

Similarly, a study in Army infantry recruits found that decreasing running mileage during basic training resulted in fewer lower extremity injuries. Jones et al. (1993) compared two different training strategies in separate Army infantry companies during 12 weeks of recruit training [18]. Both companies spent 5–6 days in physical training, spending similar time in calisthenics, stretching, drill, and ceremony; they also completed approximately 40 min of marching and running per day. However, the low running group spent only 8 of the 40 min running compared to 18 min in the high running group. At the end of the 12-week training period, the low running group ran a total of 56 miles and marched 121 miles compared to the high running company with 130 miles run and 68 miles marched. Overall, the incidence

Table 15.2 Stress fracture incidence by mileage and run time

Marines (<i>n</i>)	Total run distance (km)	Stress fracture incidence (<i>n</i> /100)	Final 3-mile run times (min)
1136	89	3.7	20.3
1117	66	2.7	20.7
1097	53	1.7	20.9

of sustaining a lower extremity injury was greater in the high running group (Risk Ratio, $RR=1.3$, 95 % Confidence Interval, $CI=1.0-1.7$). However, when combined with other training factors, such as age, cigarette use, prior history of injury, job activity, physical activity, and flexibility, the effect was diminished (Odds Ratio, $OR\ 1.6$, 95 % $CI=0.9-2.7$). Nevertheless, it is remarkable that a 57% reduction in running mileage was associated with a reduction in lower extremity injury incidence (41.8% in the high mileage group versus 32.5% in the low mileage group) without affecting overall fitness scores [1].

Another prospective cohort study in male US Navy recruits examined the impact of self-selected training load, leaving the amount of training mileage up to the discretion of the division. Out of 25 training divisions, recruits in the divisions that ran the most mileage had a significantly higher injury rate (22.4 versus 17.2%; $P<0.02$) after 8 weeks of training without any difference in overall run times in the 1.5-mile final run [19]. Results from both of these studies lend support to standardize training mileage, volume, and intensity as a way to effectively reduce the MSK-I in military training populations.

Similar studies in other countries have also shown positive results from training modifications. Several Australian military studies have demonstrated lower injury patterns with reduction of running mileage. Rudzki et al. (1997) [20] looked at 350 male recruits who were cluster randomized to a weighted march activity compared to routine standard training. The weighted group initially carried a load of 16.2 kg, with the weight progressively increased by 2.5 kg starting at week 5. The routine standard training group showed an increased risk of lower limb injury ($RR=1.65$, 95 % $CI=1.21-2.25$) and knee injuries ($RR=2.14$, 95 % $CI=1.21-3.79$) compared to the weighted march group over the 12 weeks of training. Another Australian military study prospectively followed 1634 male and 318 female recruits after changes were made to the Australian Army recruit training program. Interval runs (400–800 m) replaced road runs, test runs were reduced to 2.4 km from 5 km, route marches were standardized, and deep-water running was introduced. Following implementation, injury rates decreased to 46.6% ($\chi^2\ 14.31$, $P<0.001$) [21]. Finally, an intervention study looking at pelvic stress fractures in female Australian Army recruits also found that a multi-intervention program focusing on reduced running mileage and march speed decreased pelvic stress fractures by 91% (11.2–0.6%) from the year prior to the intervention [22].

Training Modification—Physical Readiness Training Implementation

Additional training modification studies have also demonstrated positive cardiovascular effects and injury reduction. In the US Army BCT at Fort Benning, a modified Physical Readiness Training (PRT) program was compared with the traditional physical training program, looking at injury rates and Army Physical Fitness Test (APFT) scores [23]. The new PRT intentionally decreased overall formation running mileage and included a gradual increase in distance running. The PRT program standardized basic training warm-ups and physical training and also incorporated

new evidence-based calisthenics, dumbbell drills, movement drills, interval training, and flexibility training with a progressive increase in repetitions and intensity. At the end of the 9-week BCT, the PRT group had a higher pass rate on first-time administration of the final APFT and had fewer APFT failures. Also, the PRT group, despite running 54 % fewer formation miles (17.1 miles compared to 37.2 miles), demonstrated a 52 % decrease in the overuse injury rate in males and a 46 % decrease in overuse injuries in females without having any deleterious effects on APFT run times. Even when controlling for other risk factors, there was also a significant decrease in time-loss overuse injuries in the PRT group for both males and females. Males in the traditional training group had 52 % increased risk ($RR=1.52$, 95% $CI=1.12-2.07$), while women in the traditional group had 46 % increased risk ($RR=1.46$, 95 % $CI=1.19-1.80$) of sustaining a time-loss overuse injury than the new PRT group [23].

The new PRT method was also found to be successful at reducing injury in Advanced Initial Training (AIT), or secondary training, in the Army. Similar to BCT, the traditional training group had a higher risk of a time-loss injury ($RR\ 1.5$, 95 %; $CI=1.2-1.8$) without any difference in APFT scores compared to the new PRT group [24]. These studies and others provided strong evidence for the recommendation that the new PRT should be adopted Army-wide in 2004. Since then, there has been a 21 % decrease in the injury rate compared to time period prior to the change in training during BCT/AIT.

Ankle Bracing—Athletic and Training Activities

Ankle sprains in the military occur at a rate of almost 35 sprains per 1000 person-years at risk—5 times the rate reported in civilian populations [25]. Therefore, prevention of ankle sprain has become a top priority. Ankle bracing has been shown to effectively prevent ankle injuries in several well-designed studies, especially in those who have had previous ankle sprains. A randomized controlled trial by Sitler et al. [26] on 1601 cadets at the United States Military Academy at West Point found that ankle brace use significantly reduced ankle injury during required intramural basketball. Cadets were randomized into a semirigid ankle stabilizer versus control group. They were then further randomized into a non-injured versus previously injured group and followed for 2 years. After 2 years, there were a total of 46 ankle injuries, 11 in the ankle stabilizer group and 35 in the control group ($\chi^2=12.29$; $P<0.01$). The ankle stabilizer group had a significantly lower rate of ankle sprains compared to the control group (1.6 per 1000 athlete exposures versus 5.2 per 1000 athlete exposures). Although there are always concerns from the athletes regarding performance decrement and comfort with ankle bracing, a recent study in military cadets looking at obstacle course times and dynamic lower extremity reach found no effect on performance with bracing compared to non-bracing [27].

Ankle Bracing—Parachuting

Ankle bracing has also been shown to prevent ankle injuries related to parachuting. Results of a study by Shumaker et al. [28] found that during airborne jump operations, those wearing an outside-the-boot brace had 0.6 inversion ankle injuries/1000 jumps compared to 3.8 injuries/1000 jumps for those who did not wear the brace. This translated to *three times* fewer ankle injuries in Army Rangers when wearing braces [28]. According to a recent systematic review on the effectiveness of a parachute ankle brace (PAB) overall, not wearing a PAB approximately doubled the incidence of ankle injury, ankle sprain, or ankle fracture. In addition, the calculated cost-effectiveness of a PAB showed that for every \$1 spent on the brace, \$7–9 in combined limited duty and medical costs were returned—significant savings [29]. Overall, there appears to be a significant benefit to prophylactic bracing in preventing ankle injuries during airborne training and operations, particularly in the participants with a history of previous ankle injuries.

Multiaxial, Neuromuscular, Proprioceptive, and Agility Training for Injury Prevention in Troops

Specific programs that address increasing neuromuscular control, proprioceptive, and agility training have been shown to decrease anterior knee pain, stress fracture, and other lower extremity MSK-I incidences during military training [8, 12, 30]. Anterior knee pain, or patellofemoral pain syndrome (PFPS), is a common overuse injury in the military. In United States Naval Academy midshipmen, the prevalence of PFPS upon entry to the academy is as high as 15% in females and 12% in males. Female midshipmen develop PFPS at a rate of 33/1000 person-years (95% CI=20–45/1000 person-years), while males have a rate of 15/1000 person-years (95% CI=7–22/1000 person-years) [31]. In British Army recruits, an intervention of stretching and strengthening was found to reduce PFPS during entry-level training [30]. This randomized controlled trial compared the stretching and strengthening intervention ($n=759$) to standard warm-ups ($n=743$) during the 14-week basic training cycle. The eight intervention exercises were performed as a part of regular physical training and included isometric hip abduction against a wall in standing, forward lunges, single-legged step downs, single-legged squats, quadriceps stretching, iliotibial band stretching, hamstring stretches, and calf stretches. Most importantly, an emphasis was placed on form. In total, 46 cases of diagnosed anterior knee pain were reported: 36 (4.8%) in the control group and 10 (1.3%) in the intervention group ($P<0.01$). Surprisingly, there were no gender differences noted. Perhaps, the most significant finding from this study was that despite a PFPS diagnosis, the training completion rate for those from the intervention group was 90%, while only 44% of the PFPS cases in the control group successfully completed the training [30].

Another recent study on Finnish soldiers looked at a neuromuscular training program for the reduction of overall injury rates. Exercises in the neuromuscular (NM) intervention targeted core stability and endurance, improving balance, posture, coordination and agility, lumbar control and flexibility, and mobility of the hamstrings and lower extremities. Those randomized into the NM group showed a significantly reduced risk of ankle injury during the study period (HR=0.34, 95 % CI=0.15–0.78; $P=0.01$) compared with the standard training group [32]. Also, those in the NM group tended to have less time lost from training due to MSK-Is than the control group, even when all other factors were considered [32].

Recent efforts to implement similar neuromuscular training programs are also underway in the USA, the dynamic integrated movement enhancement (DIME) program, currently in its third year of implementation at the US Military Academy at West Point, was developed from prospectively identified risk factors for lower extremity injury [5]. DIME exercises are approximately 10 min in duration and emphasize mostly on proper movement control and alignment during the nine dynamic warm-up exercises. Using a cluster randomized controlled design, 2490 freshman cadets were cluster-randomized to receive the DIME warm-up, or the traditional Army PRT active warm-up (AWU). Warm-ups were performed 2–3 times/week before regular physical activity over the 6-week summer training. Because of the importance of proper technique and performance of the DIME exercise, a portion of participants received additional DIME expert supervision (DES) from a physical therapist or athletic trainer (AT). All MSK-Is were captured via an electronic medical record system across summer training and the following 9 months. While there were no differences in overall injury rate between groups over the basic training period, there was 41 % reduction in lower extremity injury for the DES group compared to no expert supervision (RR=0.59, 95 % CI=0.38–0.93) and a non-significant 25 % decrease compared to the AWU group over the following academic year [33]. At the time of publication, this study was still ongoing, but overall, DIME exercises combined with expert supervision appear to contribute to successful injury prevention.

Successful Injury Prevention Systems

Sports Medicine and Rehabilitation Team Centers—SMART Centers

Traditional MSK-I treatment at military sites often includes 20-min booked appointments at base clinics and/or hospitals. These problem-based clinic visits frequently mean service members are seen by providers who may not have adequate training in the evaluation of and appropriate referral for MSK-Is [34]. In 2008, Marine Corps Base Camp Lejeune began the implementation of SMART at designated

musculoskeletal-only clinics. The goals of the SMART clinics were to (1) expedite return to work/duty, (2) improve health care satisfaction, and (3) reduce attrition of active duty service members. These goals were planned to be achieved through targeted improved MSK-I care access, early and accurate MSK-I diagnosis, and aggressive reconditioning.

SMART Center providers consist of primary care sports medicine-trained physicians, ATs, and physical therapists who provide team-based care in an open-bay configuration. This setup allows for an increased number of patients to be seen and lends itself to better coordinated MSK-I care. An additional benefit of this approach is a decreased number of required orthopedic consults through early diagnosis and treatment compared with the traditional model.

A comparison of electronic medical record encounters from the 2 years before and after SMART Center implementation showed that patient encounters increased an average of 41 % after SMART Center establishment [34]. Resultant orthopedic consults were decreased by 20 % in the following 2-year period. Most significantly, while MSK-Is represented 64 % of all limited duty periods that lead to physical evaluation boards, these were reduced by 9 % following SMART Center implementation. In conclusion, the open sports medicine-based concept allows for improved access to care and decreased the number of service members referred for physical evaluation boards. This success has led to the establishment of SMART Centers on most Naval and Marine Corps bases worldwide [34].

Sports Medicine Injury Prevention—SMIP in USMC

Between 1997 and 2001, approximately 1100 Marines per year were discharged from basic training due to MSK-I. Females were also more than 2 times more likely than males to have an MSK-I-related discharge. Knowing this, a concerted effort to address this problem was made in Marine Corps Basic Training—the Sports Medicine Injury Prevention (SMIP) program. First initiated at Parris Island in June 2003, SMIP focuses on MSK-I prevention, assessment, and treatment program using ATs integrated into the recruit training environment at the battalion level. The program has since been added at Marine Corps Recruit Depot San Diego and secondary training-level sites as well.

Central to the SMIP success is an injury prevention initiative that has been integrated into the Marine Corps Physical Training Instructor Course. This course targets drill instructors who are pivotal in the running of physical training sessions during recruit training and emphasizes injury prevention targeted at entry-level training. In concurrence with the Military Training Task Force recommendations, citing education and command-level involvement as essential for injury prevention success, SMIP has capitalized on this to become a seamless part of the regular training environment.

Stress Fracture Reduction System—Army Basic Training

Stress fractures in basic training (BCT) are a huge problem (see Chap. 5). A recent study looking at new recruits in the US basic training found that the incidence of stress fracture for men was 19.3 cases per 1000 recruits compared to 79.9 cases per 1000 recruits for women [35]. Lower extremity stress fractures predominate, with rising concern over problematic areas, such as the femoral neck and pelvis showing stress fractures arising more frequently in basic trainees [14]. Traditionally, recruits who suffer a lower extremity injury during BCT, including stress fracture, are placed into a Physical Training and Rehabilitation Program (PTRP), allowing them time to heal and preserving their training stage. PTRP recruits are returned to the same phase training they left from if and when they are medically cleared to return, if possible. Up to 75 % of the PTRP trainees suffer from lower extremity stress injuries. While up to 70 % of those enrolled into PTRP were able to be returned to BCT, the cost and time added can be significant [14].

Beginning in 2009, Fort Jackson medical command implemented a multifaceted injury prevention system to address the stress fracture problem [14]. Fort Jackson is the Army's largest training site, with over 40,000 basic trainees completing BCT each year. The program aimed to reduce lower extremity stress injuries and reduce the number of recruits enrolled into the PTRP. The multifaceted intervention system consisted of: (1) leadership education to garner support for the concept of injury prevention, (2) leadership enforcement of new stress fracture clinical management guidelines (Fig. 15.2), (3) implementation of the Army PRT, and (4) injury surveil-

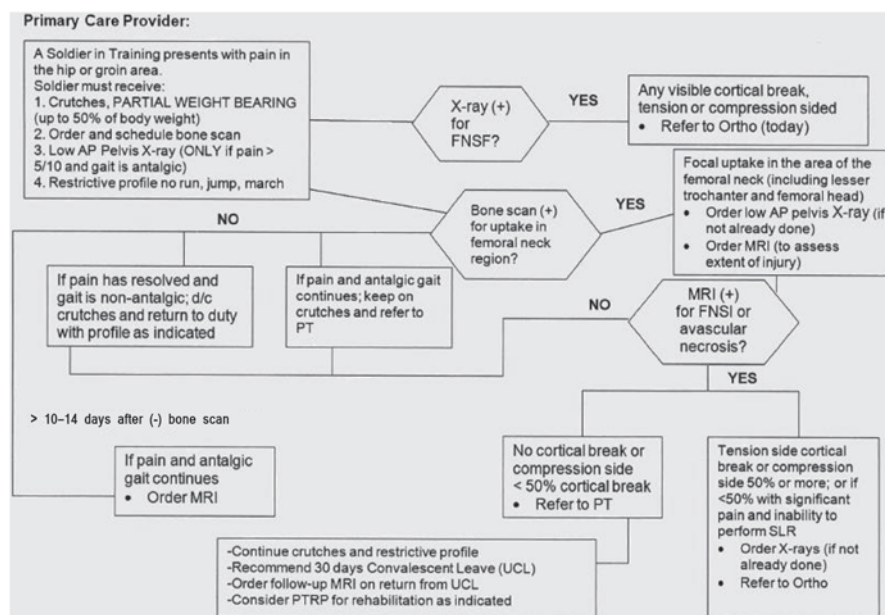


Fig. 15.2 Clinical management guidelines for hip pain at Fort Jackson, SC

lance and reporting to unit leaders and the installation safety office. With these multiple interventions, the incidence rate of femoral neck stress injury was 58% lower among men and 50% lower among women compared to previous years. The rate of referrals to the PTRP also decreased—64% in men and 57% in women. In total, there were 75 fewer cases of femoral neck stress injuries after the intervention. This was estimated to have saved the Army \$5.3 million for this injury alone.

Future Recommendations

Despite these injury prevention successes, MSK-I remains the largest health problem affecting military troops today [1]. New injury prevention efforts in several military populations are looking to focus on additional risk factors, such as biomarker identification, movement pattern identification, and movement retraining, as ways to continue to address the MSK-I challenge.

Biomarkers

Biomarkers (both biochemical and imaging) have become an active area of research as potential early indicators of MSK-I risk. Biomarkers are measured characteristics which may be used as an indicator of some biological state or condition. Cartilage degradation markers have previously been linked to incidence and progression of osteoarthritis after a traumatic injury, such as an anterior cruciate ligament (ACL) tear. But new evidence shows that higher levels of cartilage degradation biomarkers may exist prior to ACL injury in military cadets at the United States Military Academy. Finding higher levels of these biomarkers prior to injury could be used as a screening tool to identify military troops at risk for ACL and other lower extremity injuries [36].

Using Movement Screening

The financial burden and impact from MSK-Is could potentially be drastically reduced if individuals at high risk for MSK-I could be rapidly and reliably identified before training and subsequent injury. New data indicate that, in addition to previously identified physical risk factors, inadequate core stability and poor movement patterns are also major risk factors for many MSK-I in active populations, including PFPS, lower extremity stress fracture, and acute traumatic ACL injury [37–39]. Rapid and reliable screening procedures have recently been developed to prospectively and effectively screen for these factors in military environments. Screens such as the Functional Movement Screen (FMS), the Landing Error Scoring System (LESS), and the Y-Balance Test have been shown to predict injury risk

in athletic populations and are currently being used in several military populations [37, 39–43].

The FMS is a seven-step tool that assesses agility and core strength through posture screening, range of motion, muscle performance, motor control, and balance. In our previous work with Marine Officer Candidates, those scoring ≤ 14 (out of a possible 21) on the FMS were twice as likely to fail to graduate due to MSK-I versus those who scored > 14 [44]. The LESS is a validated and reliable objective clinical screen for detecting real-time high-risk jumping/landing biomechanics [39]. Our previous work shows that athletes who have abnormal LESS scores are more likely to suffer serious ankle and knee injuries as well as stress fracture [45]. The Y-Balance Test consists of the anterior, posteromedial, and posterolateral reach directions of the traditional Star Excursion Balance Test and assess dynamic balance. Reach deficits on the Y-Balance Test have been shown to be a predictor of lower extremity injury in large athletic populations [46]. By combining the most predictive components from these proven injury-screening measures, a comprehensive, robust, and trainable screening tool to successfully predict an individual's overall risk of MSK-I can potentially be developed and implemented prior to beginning basic training. Effective screening of individuals at high risk for MSK-I before basic training would allow for those identified as high risk to receive “pre-habilitation” before suffering a MSK-I. Further research is needed to investigate the effects from such interventions on the risk of MSK-I in training populations, but emerging data suggest that these screening and intervention strategies may have promise in reducing injury risk [33].

Shifting Resources to the Left

As this chapter outlines, MSK-I prevention has shown numerous successes in several military populations. Despite these successes, risk factors for injury-related discharge from basic training remain stubbornly consistent [47]. Namely, low entry physical fitness levels continue to be one of the strongest predictors of MSK-I risk during all forms of training [47–49]. While a large emphasis has been placed on preventing overtraining to ease the MSK-I burden, it has proven difficult to find ways to increase physical fitness in low-fit recruits within the traditional confines of basic training requirements and timelines. Many services allow recruits who fail the initial physical fitness test to remain at the basic training site, albeit in a separate conditioning group. While this may allow unfit recruits time to acclimatize to rigorous training standards before formally beginning basic training, there are vast personnel and financial costs associated with running these groups. Additionally, beyond basic training, MSK-I persists into secondary training and deploying military service members and is the number one cause of lost duty days, medical cost, and disability benefits in all levels of service (Fig. 15.3; 1, 50–52). New proposals to

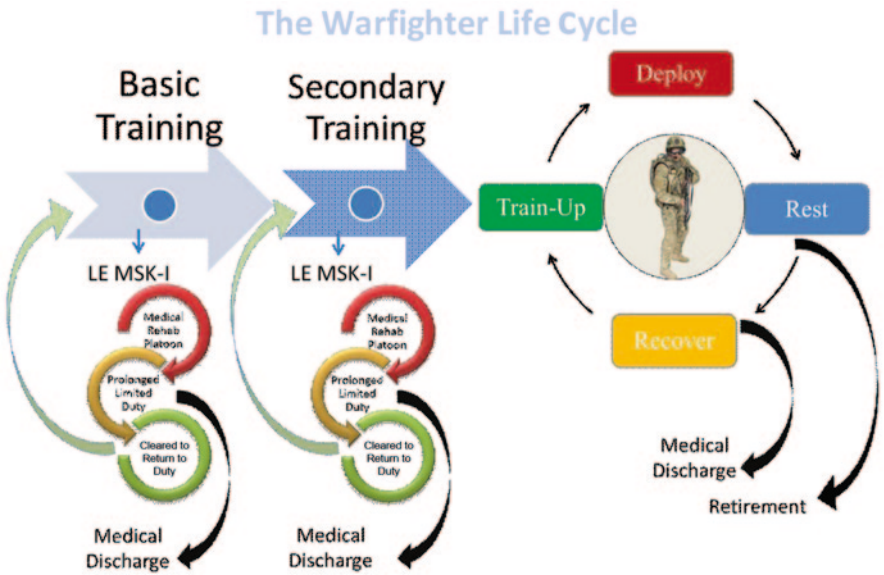
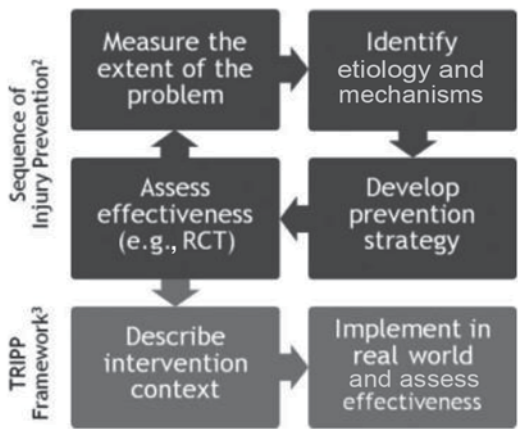


Fig. 15.3 Modern day war fighter life cycle

update accession criteria to ensure increased physical fitness in new recruits include shifting physical fitness requirements “to the left,” or before entry into active duty. Such a shift could allow for preconditioning to occur in the delayed entry process for interested applicants before the official entry into service.

Considering Implementation—A Military Advantage Recent work in MSK-I prevention has stressed the need to apply implementation science methods in order to address the broad ecological context into which programs are introduced (Fig. 15.4)

Fig. 15.4 Systematic approach to sports injury prevention



[53, 54]. Implementation science research encompasses a broad range of issues and includes the collaboration between clinicians, policy-makers, researchers, and leaderships that are all essential to carrying out successful injury prevention. Successful military injury prevention studies and systems have several advantages over civilian and sporting populations in that there is the ability to implement policy changes in the top-down military structure that results in enforced adoption of new practices from the bottom-up; however, as discussed in the following chapter, this can also be a barrier to adoption and maintenance. The injury prevention studies outlined in this chapter have all worked to implement successful evidence-based interventions along with a myriad of other shifts and/or changes in policy, ensuring the adoption of the intervention or program. They have also worked on implementing injury prevention interventions at the population level. Although rarely described in the resulting literature, these programs have also identified and addressed barriers to program implementation and adoption in coordination with the development of the intervention. Through their experience in developing and implementing the DIME (see above), the JUMP-ACL group have described seven additional steps for designers and implementers of preventive training programs to consider [5]. As the authors suggest, the key to successful implementation is the development of an interdisciplinary team to identify barriers and potential solutions *before* the development of the injury prevention intervention [5]. By identifying and addressing barriers to implementation that inform the program development, the resulting adoption and use of the intervention seeks to alter the environmental and behavioral factors that are critical to successful injury prevention (Fig. 15.5) [53, 54]. This chapter specifically addresses a framework and strategies to overcome the barriers to implementing MSK-I prevention interventions in military settings.

Fig. 15.5 Implementation drivers



Conclusions

Injury prevention in the military has had numerous successes over the years and has benefitted from lessons learned along the way. Specific MSK-I prevention interventions in this population have primarily focused on specific strategies and/or specific systems to address the problem, with policy changes also aiding efforts. By focusing on six main principles, MSK-I rates in basic training and other military populations have been decreased. Through the use of secondary prevention and system approaches, successfully preventing MSK-Is in the military is a known force multiplier. Prevention of overtraining, utilization of ankle bracing, and targeted neuromuscular training all have proven effective in injury prevention in several military populations. Though these programs have shown evidence of efficacy in various military training settings, the effectiveness of these programs in real-world settings can be a challenge. Future trends include research into biomarkers that may be indicative of increased injury risk, utilizing movement screening strategies, and shifting resources to the left. Finally, the structure of the military can also be advantageous in the implementation of any injury prevention intervention but still needs leadership support for successful integration and long-term results. Furthermore, for behavioral interventions to be sustainable, strategies to encourage voluntary adoption in the target population will likely be necessary.

Disclaimer All authors are employees of the US Federal Government and the US Army. The opinions or assertions contained herein are the private ones of the author(s) and are not to be construed as official or reflecting the views of the Uniformed Services University, Department of the Army, or the US Department of Defense.

References

1. Hauret KG, Jones BH, Bullock SH, Canham-Chervak M, Canada S. Musculoskeletal injuries description of an under-recognized injury problem among military personnel. *Am J Prev Med.* 2010;38:S61–70.
2. Jones BH, Canham-Chervak M, Sleet DA. An evidence-based public health approach to injury priorities and prevention recommendations for the U.S. Military. *Am J Prev Med.* 2010;38:S1–10.
3. Bullock SH, Jones BH, Gilchrist J, Marshall SW. Prevention of physical training-related injuries recommendations for the military and other active populations based on expedited systematic reviews. *Am J Prev Med.* 2010;38:S156–81.
4. Steffen K, Meeuwisse WH, Romiti M, et al. Evaluation of how different implementation strategies of an injury prevention programme (FIFA 11+) impact team adherence and injury risk in Canadian female youth football players: a cluster-randomised trial. *Br J Sports Med.* 2013;47:480–7.
5. Padua DA, Frank B, Donaldson A, et al. Seven steps for developing and implementing a preventive training program: lessons learned from JUMP-ACL and beyond. *Clin Sports Med.* 2014;33:615–632.

6. Altarac M, Gardner JW, Popovich RM, Potter R, Knapik JJ, Jones BH. Cigarette smoking and exercise-related injuries among young men and women. *Am J Prev Med.* 2000;18:96–102.
7. Jones BH, Knapik JJ. Physical training and exercise-related injuries. Surveillance, research and injury prevention in military populations. *Sports Med.* 1999;27:111–25.
8. Molloy JM, Feltwell DN, Scott SJ, Niebuhr DW. Physical training injuries and interventions for military recruits. *Mil Med.* 2012;177:553–8.
9. Knapik JJ, Hauret KG, Jones BH. Primary prevention of injuries in initial entry training. In: DeKoning B, editor. *Recruit medicine*. Washington, DC: Office of The Surgeon General, Department of the Army; 2006:125–46.
10. Bahr R, Holme I. Risk factors for sports injuries—a methodological approach. *Br J Sports Med.* 2003;37:384–92.
11. Cameron KL. Commentary: time for a paradigm shift in conceptualizing risk factors in sports injury research. *J Athl Train.* 2010;45:58–60.
12. Brushoj C, Larsen K, Albrecht-Beste E, Nielsen MB, Løye F, Holmich P. Prevention of overuse injuries by a concurrent exercise program in subjects exposed to an increase in training load: a randomized controlled trial of 1020 Army recruits. *Am J Sports Med.* 2008;36:663–70.
13. Knapik JJ, Darakjy S, Hauret KG, et al. Increasing the physical fitness of low-fit recruits before basic combat training: an evaluation of fitness, injuries, and training outcomes. *Mil Med.* 2006;171:45–54.
14. Scott SJ, Feltwell DN, Knapik JJ, et al. A multiple intervention strategy for reducing femoral neck stress injuries and other serious overuse injuries in U.S. Army basic combat training. *Mil Med.* 2012;177:1081–9.
15. Sherrard J, Lenne M, Cassell E, Stokes M, Ozanne-Smith J. Injury prevention during physical activity in the Australian Defence Force. *J Sci Med Sport.* 2004;7:106–17.
16. Shaffer RA. Musculoskeletal injury project. Paper presented at: American College of Sports Medicine; 1996, 1996; Cincinnati, OH.
17. Knapik J, Hauret KG, Jones BH. Primary prevention of injuries in initial entry training. In: Lenhart M, Institute B, editor. *Recruit medicine*. Washington, DC: Office of The Surgeon General at TMM Publications; 2006.
18. Jones BH, Cowan DN, Tomlinson JP, Robinson JR, Polly DW, Frykman PN. Epidemiology of injuries associated with physical training among young men in the Army. *Med Sci Sports Exerc.* 1993;25:197–203.
19. Capacchione JF, Muldoon SM. The relationship between exertional heat illness, exertional rhabdomyolysis, and malignant hyperthermia. *Anesth Analg.* 2009;109:1065–9.
20. Rudzki SJ. Injuries in Australian Army recruits. Part I. Decreased incidence and severity of injury seen with reduced running distance. *Mil Med.* 1997;162:472–6.
21. Rudzki SJ, Cunningham MJ. The effect of a modified physical training program in reducing injury and medical discharge rates in Australian Army recruits. *Mil Med.* 1999;164:648–52.
22. Pope RP. Prevention of pelvic stress fractures in female Army recruits. *Mil Med.* 1999;164:370–3.
23. Knapik JJ, Hauret KG, Arnold S, et al. Injury and fitness outcomes during implementation of physical readiness training. *Int J Sports Med.* 2003;24:372–81.
24. Knapik JJ, Bullock SH, Canada S, et al. Influence of an injury reduction program on injury and fitness outcomes among soldiers. *Inj Prev.* 2004;10:37–42.
25. Cameron KL, Owens BD, DeBerardino TM. Incidence of ankle sprains among active-duty members of the United States Armed Services from 1998 through 2006. *J Athl Train.* 2010;45:29–38.
26. Sitler M, Ryan J, Wheeler B, et al. The efficacy of a semirigid ankle stabilizer to reduce acute ankle injuries in basketball. A randomized clinical study at West Point. *Am J Sports Med.* 1994;22:454–61.

27. Newman T, Croy T, Hart J, Saliba S. The effects of prophylactic ankle bracing on dynamic reach distance and obstacle course performance in military cadets. *Mil Med.* 2012;177:567–72.
28. Schumacher JT Jr, Creedon JF, Pope RW. The effectiveness of the parachutist ankle brace in reducing ankle injuries in an airborne ranger battalion. *Mil Med.* 2000;165:944–8.
29. Knapik JJ, Spiess A, Swedler DI, Grier TL, Darakjy SS, Jones BH. Systematic review of the parachute ankle brace: injury risk reduction and cost effectiveness. *Am J Prev Med.* 2010;38:S182–8.
30. Coppack RJ, Etherington J, Wills AK. The effects of exercise for the prevention of overuse anterior knee pain: a randomized controlled trial. *Am J Sports Med.* 2011;39:940–8.
31. Boling M, Padua D, Marshall S, Guskiewicz K, Pyne S, Beutler A. Gender differences in the incidence and prevalence of patellofemoral pain syndrome. *Scand J Med Sci Sports.* 2010;20:725–30.
32. Parkkari J, Taanila H, Suni J, et al. Neuromuscular training with injury prevention counseling to decrease the risk of acute musculoskeletal injury in young men during military service: a population-based, randomised study. *BMC Med.* 2011;9:35.
33. Carow S, Haniuk E, Cameron K, et al. Risk of lower extremity injury in a military cadet population after a supervised injury-prevention program. *J Athl Train.* 2014;49. doi:10.9085/1062-6050-49.522.
34. Brawley S, Fairbanks K, Nguyen W, Blivin S, Frantz E. Sports medicine training room clinic model for the military. *Mil Med.* 2012;177:135–8.
35. Knapik J, Montain SJ, McGraw S, Grier T, Ely M, Jones BH. Stress fracture risk factors in basic combat training. *Int J Sports Med.* 2012;33:940–6.
36. Svoboda SJ, Harvey TM, Owens BD, Brechue WF, Tarwater PM, Cameron KL. Changes in serum biomarkers of cartilage turnover after anterior cruciate ligament injury. *Am J Sports Med.* 2013;41:2108–16.
37. Boling MC, Padua DA, Marshall SW, Guskiewicz K, Pyne S, Beutler A. A prospective investigation of biomechanical risk factors for patellofemoral pain syndrome: the joint undertaking to monitor and prevent ACL injury (JUMP-ACL) cohort. *Am J Sports Med.* 2009;37:2108–16.
38. Kiesel K, Plisky PJ, Voight ML. Can serious injury in professional football be predicted by a preseason functional movement screen? *N Am J Sports Phys Ther.* 2007;2:147–58.
39. Padua DA, Marshall SW, Boling MC, Thigpen CA, Garrett WE Jr, Beutler AI. The landing error scoring system (LESS) is a valid and reliable clinical assessment tool of jump-landing biomechanics: the JUMP-ACL study. *Am J Sports Med.* 2009;37:1996–2002.
40. Kiesel K, Plisky P, Butler R. Functional movement test scores improve following a standardized off-season intervention program in professional football players. *Scand J Med Sci Sports.* 2009;21:287–292.
41. Shaffer SW, Teyhen DS, Lorensen CL, et al. Y-balance test: a reliability study involving multiple raters. *Mil Med.* 2013;178:1264–70.
42. Teyhen DS, Shaffer SW, Lorensen CL, et al. The Functional Movement Screen: a reliability study. *J Orthop Sports Phys Ther.* 2012;42:530–40.
43. Teyhen DS, Shaffer SW, Lorensen CL, et al. Reliability of lower quarter physical performance measures in healthy service members. *US Army Med Dep J.* 2011;37–49.
44. O'Connor F, Deuster P. Functional movement screening (FMS) in Marine Corps officer candidate school training: is there a correlation between FMS scores and musculoskeletal injury? *Med Sci Sports Exerc.* 2011;43:2224–2230.
45. Cameron KL. Utility of the landing error scoring system (LESS) in screening for lower extremity stress fracture risk. Paper presented at: Society of Military Orthopaedic Surgeons; December 8–10, 2013; Vail, CO.
46. Plisky PJ, Rauh MJ, Kaminski TW, Underwood FB. Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *J Orthop Sports Phys Ther.* 2006;36:911–9.

47. Swedler DI, Knapik JJ, Williams KW, Grier TL, Jones BH. Risk factors for medical discharge from United States Army Basic Combat Training. *Mil Med.* 2011;176:1104–10.
48. Trank TV, Ryman DH, Minagawa RY, Trone DW, Shaffer RA. Running mileage, movement mileage, and fitness in male U.S. Navy recruits. *Med Sci Sports Exerc.* 2001;33:1033–8.
49. Trone DW, Cipriani DJ, Raman R, Wingard DL, Shaffer RA, Macera CA. The association of self-reported measures with poor training outcomes among male and female U.S. Navy recruits. *Mil Med.* 2013;178:43–9.
50. Grier TL, Knapik JJ, Canada S, Canham-Chervak M, Jones BH. Risk factors associated with self-reported training-related injury before arrival at the US Army ordnance school. *Public Health.* 2010;124:417–23.
51. Hauret KG, Taylor BJ, Clemmons NS, Block SR, Jones BH. Frequency and causes of non-battle injuries air evacuated from operations Iraqi freedom and enduring freedom, U.S. Army, 2001–2006. *Am J Prev Med.* 2010;38:S94–107.
52. Rivera JC, Wenke JC, Buckwalter JA, Ficke JR, Johnson AE. Posttraumatic osteoarthritis caused by battlefield injuries: the primary source of disability in warriors. *J Am Acad Orthop Surg.* 2012;20(Suppl 1):S64–9.
53. Donaldson A, Finch CF. Applying implementation science to sports injury prevention. *Br J Sports Med.* 2013;47:473–5.
54. Finch CF. No longer lost in translation: the art and science of sports injury prevention implementation research. *Br J Sports Med.* 2011;45:1253–7.

Chapter 16

Overcoming Barriers to Injury Prevention in the Military

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Scott W. Shaffer, and Nikki Butler

Introduction

Healthy People 2020 has identified a wide variety of public health concerns that threaten the population of the USA [1, 2]. Some of the top concerns include obesity, diabetes, physical inactivity, musculoskeletal injury, mental health issues, and inadequate sleep hygiene. In response, health-care experts have developed a number of evidence-based interventions across a wide variety of settings to help prevent and/or mitigate these risks. While many of these interventional programs have demonstrated efficacy in clinical studies, successful implementation of these programs on a community, state, and national scale has often proven elusive [3, 4].

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287

Musculoskeletal injuries are of particular concern in the military setting as they adversely impact physical performance as well as individual and unit readiness. Musculoskeletal health conditions and subsequent long-term disability cost the Department of Defense (DoD) billions in health-care dollars [5]. In order to reverse this trend, the DoD and military medicine should collaboratively implement and sustain effective injury surveillance, injury prediction screening, evidence-based physical training, and other interventions that reduce musculoskeletal injuries while optimizing human performance and health. Proven injury prevention and health promotion practices that reach the right population with the right intervention at the right time are critical if we are to reduce the impact of injuries long term [6].

Translating health promotion and injury prevention research into practice in a timely manner to improve combat readiness, decrease injuries, and optimize performance is critical. Standard research efforts in controlled environments with high internal validity produce valuable results and are often touted as the “gold standard” [7]. However, translating efficacious injury prevention principles and best practices from research studies to a real-world setting such as the battlefield or across the different components of the military (Active Duty, Reserve, or National Guard) is complex and often not as effective due to the limited external validity of these programs [8]. The Translating Research into Injury Prevention Practice (TRIPP) framework outlines seven steps to facilitate this process: (1) understand the etiology of injuries, (2) develop programs that address mechanism of injury, (3) conduct research to demonstrate efficacy in a controlled setting (internal validity), (4) understand the behavior and environment of the target audience, (5) modify the intervention to address the needs of the target audience, (6) develop implementation and safety strategies to facilitate application in real-world settings, and (7) measure effectiveness of the program in the applied environment (external validity) [9].

Ultimately, a multifaceted injury prevention strategy that is feasible, accessible, and sustainable is required to address the reality faced in implementing injury prevention programs in more complex settings. Common barriers to implementing a successful health promotion and injury prevention program were first introduced by Dr. Russell E Glasgow and associates in 1999 [3, 8]. The RE-AIM model evaluates public health interventions across five dimensions: (1) *reach*, (2) *efficacy/effectiveness*, (3) *adoption*, (4) *implementation*, and (5) *maintenance* (Fig. 16.1). Thus, in order to assess the potential barriers and impacts of a public health policy, program, or intervention, one must evaluate each of these dimensions. “Failure to adequately evaluate programs on all five dimensions can lead to a waste of resources, discontinuities between stages of research and failure to improve public health to the limits of our capacity” [8].

In the military setting, other barriers exist that may prevent wide-scale *adoption* of injury prevention and health promotion interventions that have proven to be *effective* over time. These barriers exist at the: (1) corporate or strategic level (policy makers, senior officials, etc.), (2) organizational or operational level (medical treatment facilities, operational level units, etc.), and (3) individual or tactical

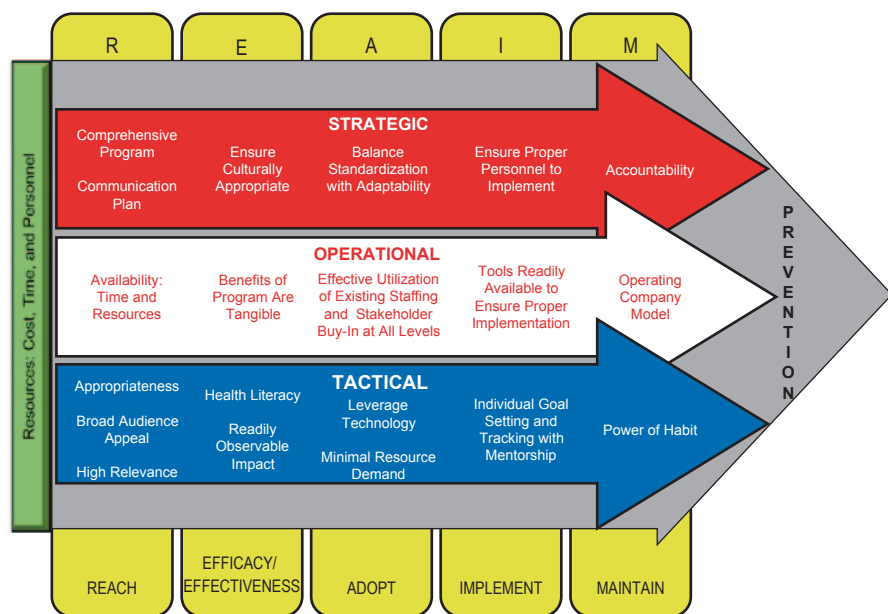


Fig. 16.1 Application of RE-AIM model to overcoming barriers to injury prevention in the military setting

level (health-care providers, service members, family members, tactical level units, etc.). Therefore, this chapter addresses barriers to injury prevention with respect to the RE-AIM model at these three levels.

Overview of the RE-AIM Model

In 1999, the *reach, efficacy/effectiveness, adoption, implementation, and maintenance* (RE-AIM) model was described by Glasgow et al. [4, 8] in an effort to identify the breadth of influences that promote the success or failure of health promotion efforts. They argue that the multitude of *efficacy* studies conducted with subjects, settings, and/or interventions that are biased toward the success of the proposal are destined to fail when applied outside the controlled setting of the research. Glasgow et al. also stress that the intervention proposal should include a plan to address all five of the major dimensions of RE-AIM. The specificity of these dimensions has made the RE-AIM model an exceptional framework around which program analysis and evaluation can be built in health promotion and injury prevention.

The RE-AIM model includes parameters addressing the micro or individual aspects of program success: *reach* and *efficacy/effectiveness*, as well as parameters focused on the implementing organization or setting: *adoption, implementation, and maintenance*. Glasgow and his coauthors [8] define *reach* as the num-

ber/percentage of all appropriate individuals that participate in the intervention as well as a critique of their representativeness of the population as a whole (e.g., age, gender, socioeconomic status, literacy, severity of condition). They emphasize the importance of accurately identifying the true size of the applicable population to appropriately gauge the degree of *reach*. The *efficacy or effectiveness* criterion addresses the measureable impact on the chosen outcome measure as demonstrated by high-quality evidence. These two criteria as well as the others are considered multiplicative factors whose interaction can significantly impact expected outcomes. For example, a health promotion program aimed at reducing childhood obesity that demonstrated 80% *effectiveness* at reducing body mass index (BMI) in a controlled/funded research effort but only reaches 15% of 1000 potential beneficiaries in a community effort is only successful in 120 people. Similarly, a less *effective* (40%) intervention that reaches 80% of potential beneficiaries is ultimately successful in 320 people [8].

Adoption is the first organizational level criterion and is defined as the number/percentage of “settings” that elect to implement the chosen program [8]. This criterion also includes commentary on the representativeness of those that participate compared to those settings that elect not to participate. These comparisons should include comments regarding staffing, funding, and facilities in order to accurately identify barriers to broader *implementation*. *Implementation* refers to the degree to which the selected program is delivered to the intended audience in accordance with the defined protocol. *Implementation* can be enumerated as successful participant contacts, percentage of times content is delivered accurately, or number/percentage of staff across settings that elect to participate. Similar to other criteria, it is important to identify characteristics of those staff that are compliant and consistently deliver content or choose to participate. Are those that participated representative of all personnel? How do they compare to published results or standards?

The final criterion of the RE-AIM model is *maintenance*. *Maintenance* has applicability at both the individual and organizational (setting) levels. Organizationally, *maintenance* refers to the long-term incorporation of the intervention into the daily practice, culture, and corporate policies greater than 6 months beyond the original *implementation* period [4]. Individually, *maintenance* can be reported as long-term (>6 months) incorporation of promoted behaviors by percentage attrition.

The breadth and depth of analysis encouraged by the RE-AIM model provides a strong foundation for addressing barriers to successful *implementation* of injury prevention and health promotion programs. Using this model to review the health promotion and injury prevention efforts implemented by the US military and those of partner nations helps to identify barriers to successful mitigation of their public health concerns (e.g., impaired mental health, obesity, musculoskeletal injury, poor sleep hygiene, suicide). The remainder of this chapter is dedicated to the application of the RE-AIM framework as an evaluation tool to review a variety of health promotion and injury prevention efforts in the military setting. We will identify individual and corporate barriers at the strategic, operational, and tactical levels and make recommendations regarding future program development and *implementation* that will improve observed outcomes.

R: Reach the Target Population

Reach is the first step in the RE-AIM model and is defined as an individual measure of participation [8]. *Reach* is the absolute number or percentage of target audience and representativeness of individuals who know about the initiative and are willing to participate in a given initiative [8]. On the surface, *reach* in a military setting appears easy as unit leaders can mandate that service members participate in approved, sanctioned programs. However, programs that are mandated often undermine *adoption* and long-term behavior change required for the program *maintenance*. For example, fitness programs are often mandated for active duty service members to help maintain readiness, including maintenance of physical performance requirements and height/weight standards. Despite years of program compliance, upon discharge from the military the average service member gains weight at a higher rate than active duty service members. Specifically, around the time of discharge from the military, men and women gain 12.6 or 13.9 lbs on average, respectively [10]. Higher rates of being physically inactive, smoking, alcohol consumption, and diabetes have also been reported after discharge from the military, when programs are no longer mandated [11]. Additionally, in the military setting, *reach* is often limited due to a diminished understanding of what programs and resources are available in the local environment. This is complicated by the high operational tempo, limited time due to competing demands, and a lack of leadership support for some of the programs. *Reach* in a military setting is also complicated by the fact that service members typically change duty locations every 3–4 years. Efforts to ensure similar resources are available across installations and can assist with maximizing awareness and ultimately the *reach* of an injury prevention program. With that in mind, the success of reaching the target population depends upon a greater understanding of the characteristics of the target population, specifically the psychosocial and medical history. For example, a history of previous musculoskeletal injury is one of the single most significant risk factors for subsequent injury, but this information is rarely relayed to unit commanders when service members change duty stations, which can limit the reach of injury prevention efforts.

Strategic-Level Barriers

A comprehensive injury prevention program that incorporates injury surveillance, injury prevention, early intervention, reintegration, and human performance optimization can help maximize *reach* through rapid identification and risk mitigation strategies. Recently the Army developed the Musculoskeletal Action Plan (MAP) [12]. The goal of the MAP was to provide a strategic framework to assess and address the impact of injuries on the military and to translate evidence-based interventions into standardized practices across military installations. By standardizing practices across Army Medicine, the MAP also helped to bring an Operating Company Model framework to the enterprise [13]. This framework establishes

consistency across the organization, clarity in the standards and how the enterprise supports them, and a linkage between performance and outcomes/goals of the organization. A key aspect to standardizing practice across an organization such as the US military is a well-constructed communication strategy. The communication strategy should heighten awareness and provide guidance on how to access the resources to facilitate the *reach* of any injury prevention, performance optimization, or health promotion initiative.

Operational-Level Barriers

A program's success at the organizational/operational level is dependent upon cooperation between the medical community and the unit leadership. The willingness of leaders at all levels to support efforts focused on improving medical readiness by investing time and resources is critical to decrease injuries and optimize performance. Organizational success requires a stepwise process be initiated. The first step is to implement a surveillance program that facilitates a thorough analysis of the extent of the problem while simultaneously identifying injury trends. Injury surveillance programs, in which results can be applied at the local level (i.e., military unit), are critical to gain the fidelity required for effective injury prevention programs. The second step is to identify gaps and perform a needs assessment of the entire population within the organization, paying particular attention to subgroups that are at the greatest risk. Units have a variety of assigned medical assets that can assist in this effort. In particular, the combat brigades have physical therapists who are taught how to implement surveillance techniques, develop injury prevention/human performance optimization programs as well as identify and treat musculoskeletal injuries. Although the brigade physical therapists can help lead an injury prevention effort, a well-designed program capitalizes on the knowledge, skills, and attributes of the entire medical team—to include the physicians, physician assistants, physical therapy technicians, medics, behavioral health providers, and nurses. With the support of the medical and unit leadership, this unique team of providers can maximize the time and minimize the external resources necessary to implement programs that will ultimately decrease injuries, optimize performance, and improve the overall medical readiness of the unit.

There are a variety of tools used for injury prediction with varying degrees of success [14–17]. Currently, the Army is conducting field research at the unit level to determine the most parsimonious set of tests to predict injury risk [18]. In addition to identifying individual risk factors for injury, a unit-facilitated injury prediction screening program can assist in providing information to mitigate injury risk at the organizational level. This can be powerful as it provides guidance to unit leaders in modifying and optimizing physical training programs by incorporating injury prevention exercises and techniques targeted at high-risk individuals and activities.

Once an injury occurs, early intervention is paramount in decreasing the number of lost duty days and long-term disability [5]. Thus, operational-level leadership needs to facilitate and encourage service members to seek care for an injury as targeted intervention and rehabilitation must *reach* the right injured population at the right time to have the desired outcome. Standardization at the operational level is a key to the success of these programs to help facilitate a quick return back to the unit.

Often, the injured service member cannot physically perform to the same level as the healthy population; if there is no program available that bridges the gap between the medical treatment facility treatment protocol and the return to normal unit activity, the service members risk reinjury [19, 20]. Thus, units should also develop programs that address the needs of this vulnerable population. Regardless of the program(s) chosen, it is clear that it must appeal across a broad spectrum using a variety of mediums in order to address the needs of the injured and non injured population.

Tactical-Level Barriers

The appropriateness of any program depends upon identifying the right individuals in the right environment at the right time and delivering that program in the right medium in order for it to achieve the desired outcomes. This is challenging, particularly since units tend to do organized physical training that may not incorporate ability groups. Furthermore, most units do not allow service members to do individual training programs during “unit” physical training hours. This challenge may be mitigated with establishing programs that assess the physical demands required to perform in a specific Military Occupational Specialty (MOS) and then designing a training regimen that meets those requirements. The Canadian military has piloted an online program which allows individual training of geographically separated individuals based on the physical demands of the MOS. By having a program that is both standardized, yet tailored to the individual’s needs, this program may ultimately improve the *reach* across multiple military settings (Active Duty, Reserve, and National Guard) and enhance injury prevention and human performance optimization efforts (www.DFit.ca).

Determining the appropriate *reach* is critical in establishing a program that meets the needs of the entire population served and, in particular, those with the greatest injury risk. Historically, the DoD designs programs for the masses, targeting the average healthy service member and often neglects programs that prevent injury or optimize performance. An integrated plan that addresses strategic, operational, and tactical barriers to *reach* can be utilized to optimize participation in injury prevention programs. A summary of potential barriers and solutions to enhance the *reach* of injury prevention and performance optimization is provided in Table 16.1.

Table 16.1 Potential barriers and solutions to enhance *reach* for the target population in military injury prevention programs [21]

Potential barrier	Potential solutions
Lack of knowledge of the program	An effective communication strategy that ensures appropriate dissemination of the information is required. Utilization of the operating company model across installations will help enhance reach by standardizing programs and availability at each installation
Appropriate programming to meet the needs of the population	A comprehensive program includes implementing a surveillance program and utilizing a stratification system to properly identify groups who are (1) injured/profiled, (2) recovering from injury, (3) healthy. In all cases prevention of injury or reinjury is paramount
Minimize time requirements	Incorporating programs during existing training will minimize additional time requirements. Injury prevention programs can be incorporated as part of unit physical training, squad leader training, and Sergeant's Time Training to decrease the time burden and improve reach
Deconflict schedule	Published program schedules that allow service members to utilize the appropriate venue depending on their needs: gym, pool, etc.
Support and knowledge of unit leadership	Develop support from unit leadership for the programs through professional development programs and informational handouts. Training material focused on leaders should clearly highlight the benefits to participation
Recruitment and training of unit leadership	Identification of key unit leaders to facilitate the entire program from prevention to recovery to performance optimization while simultaneously incorporating prevention strategies to avoid injury or reinjury is essential to ultimately optimizing the reach of the program. Ensuring the key unit leaders are appropriately trained to implement the program successfully should enhance the ultimate reach of an ongoing and sustaining program
Identifying the correct target audience	Development of a process to identify those at higher risk for injury is essential for determining the proper denominator for an injury prevention program. Injury prevention programs that target all individuals may have limited success due to recruitment of individuals already at low risk for injury and therefore limited engagement and utilization of the program

E: Efficacy/Effectiveness

Effectiveness refers to the ability of the program to generate appropriate positive change in health and injury prevention, resulting in a positive impact on quality of life, performance, and military readiness. Abraham et al. [22] described the impact of a prevention program as a combination of the program's *reach* and its *effectiveness* ($I = R \times E$). Although evidence-based interventions that prevent injuries may have *efficacy* in a specific target population under controlled conditions, the *effectiveness* of delivering that program to a wider audience in real-world settings may not have the same results. While it is necessary for *effective* programs to have demonstrated *efficacy*, the program *efficacy* is not sufficient for programs to be *effective* in real-world settings. Specifically, *effective* injury prevention interventions should produce robust effects across multiple subpopulations and settings. Additionally, an *effective* program should have minimal to no adverse outcomes. Individuals developing injury prevention programs should account for the unanticipated negative effects that might be associated with labeling an individual at increased risk for injury and requiring additional or remedial training [23, 24].

Strategic-Level Barriers

One of the fundamental strategic imperatives is that evidence-based and *effective* programs are implemented for the target population [8]. Development of measures of performance (MOPs) and measures of effectiveness (MOEs) are essential tasks at the strategic level in optimizing program *effectiveness*. MOPs include measures of how the program was implemented and how the individual responded to the program. MOPs often help determine if the program resulted in changes in knowledge, attitudes, or beliefs. MOEs include outcome measures related to quality of life, performance, injury rates, disability, and military readiness.

Historically, most injury prevention programs in a military setting have focused on the training environment US Army Training and Doctrine Command (TRA-DOC) [25–27]. Although these training programs have demonstrated *efficacy*, the environment TRA-DOC is strictly controlled and the training regimens are often dictated. Therefore, when leaders apply lessons learned from injury prevention programs in the operational environment (Forces Command, FORSCOM), appropriate MOPs and MOEs are required to help ensure the program is *effectively* implemented in the new environment. Appropriately developed and implemented MOPs and MOEs allow for lessons learned to be captured to enhance long-term program *effectiveness*. Additionally, standardized MOPs and MOEs allow for comparative *effectiveness* of programs to be assessed across multiple environments. Finally, injury risk is multifactorial (environment, physiological, mental resilience, neuromuscular control, strength/endurance, stress, sleep, and nutrition) [28, 29]. Effective MOPs and MOEs would afford leaders at the strategic, operational, and

tactical levels the ability to troubleshoot areas that need to be reinforced to maximize program *effectiveness*.

Operational-Level Barriers

At the operational level, leaders need evidence that the program is *effective* in order to implement and maintain the program over time. The leaders have to view the program as valuable and that *implementation* is worth the time and organizational investment. This is problematic as most injury prevention programs measure changes in the short term (6 months to 1 year) in a very specific and well-defined population [30–32]. These results may be less tangible when applied to a broader audience over longer periods of time [3]. Therefore, *efficacious* injury prevention programs ultimately need to demonstrate their *effectiveness* at the operational level with diverse populations under less controlled and more real-life settings.

Tactical-Level Barriers

Injury prevention and human performance optimization program success at the individual and tactical level has proven elusive. A potential barrier to both the *reach* and *effectiveness* of such programs is the health literacy of the broadly intended audience. Health literacy is the “capacity to obtain, process and understand basic health information and services needed to make appropriate health decisions” [33]. With respect to the *RE-AIM* model, health literacy pertains to *reach* both through the capacity to “obtain” health information and the ability to “process and understand” that directly affects *efficacy* and *effectiveness* of a program.

The 2003 National Assessment of Adult Literacy (NAAL) conducted by the US Department of Education identified health literacy issues across the full spectrum of otherwise literate Americans [34]. This direct assessment of 19,000 Americans’ ability to read, comprehend, and complete health-related literacy tasks reported that upwards of 36% of those tested demonstrated basic or below basic health literacy. Effectively, those testing at these levels range between being nonliterate in English through the ability to read and understand “information in short, commonplace prose texts.” Stated another way, 36% of those tested would be unable to “determine a healthy weight range for a person of a specified height, based on a graph that relates height and weight to body mass index (BMI)” [34]. Failure to operate at this level of health literacy in more than one third of the general audience is a significant challenge to *reach* by itself, but considering that there is a selection bias in those that volunteer to participate in research such as the NAAL, the results may underestimate the percentage of the general population with basic or below basic health literacy.

Due to the literacy and language skill requirements for entry into military service, the measured health literacy of military members is slightly higher than average, with 33 % operating at basic or below basic levels [34]. That being said, other subgroups of the military beneficiary population such as retirees over 65 years of age and military community members without any college or vocational education are more likely to have basic or below basic health literacy with 59 and 44 %, respectively. Further, those whose primary language was not English before attending school had an average health literacy score of below basic. These literacy challenges significantly affect the ability of health promotion, injury prevention, and performance optimization efforts to *reach* and achieve reported *effectiveness* levels.

Overcoming the barriers of health literacy in health promotion, injury prevention, and performance optimization programs in both military and community settings requires a multifactorial approach. Prose text should be written at the lowest possible reading level, available in a variety of languages, and be supported by simple imagery that effectively supports understanding of the text. PlainLanguage.gov is a clearing house for information organized to promote the development of government information that more effectively delivers the intended messages. They encourage clear and precise information written at a reading level appropriate for the audience that is delivered in short, active voice sentences and short paragraphs with descriptive headings (www.plainlanguage.gov/howto/guidelines/FederalPLGuidelines/FederalPLGuidelines.pdf).

Literacy challenges can also be mitigated through the delivery of materials through multimedia outlets that enhance simple prose with animation or video supplements. Components of the DoD are utilizing interactive web portals to deliver a variety of health promotion messages and supplementary materials (e.g., <https://armyfit.army.mil> and <http://hprc-online.org>). While appropriate for the typically technology savvy service member, this approach for an injury prevention program may fail to *reach* the elderly and those of lower socioeconomic status. These groups are typically of the lowest health status, and thereby, in greatest need of the information [34].

Although selection of evidence-based injury prevention programs is often the first step in *implementation*, it is not sufficient to ensure *efficacy* and *effectiveness*. Strategic leaders need to develop effective MOPs/MOEs to ensure proper *implementation* and lessons learned to allow for proper modifications and adaptation based on the different subpopulations and environments. Strategic and organizational leaders can utilize these MOPs/MOEs to validate the cost, time, and personnel required to maintain the program *effectiveness* over time (Table 16.2). Finally, at the tactical level, evidence-based programs need to address the health literacy of the target population to ensure *efficacy* and *effectiveness* of the program. An integrated plan that incorporates strategic, operational, and tactical barriers to *implementation* of *effective* programs can be utilized to optimize outcomes of injury prevention, health promotion, and performance optimization programs. A summary of potential barriers and solutions to enhance *efficacy* and *effectiveness* of injury prevention programs is provided in Table 16.2.

Table 16.2 Potential barriers and solutions to enhance *efficacy and effectiveness* in military injury prevention programs [3, 21]

Potential barrier	Potential solutions
Knowledge, attitudes, and beliefs	Measures of performance (MOP) allow leaders to determine if the program is effectively changing knowledge, attitudes, and beliefs. These often change prior to behavior change and health outcomes
Appropriately selected and measured health outcomes	Measures of effectiveness (MOE) allow leaders to determine if the program is having a positive or negative impact on health and readiness
Sustainability	Lack of MOPs/MOE may lead to an effective program being cancelled. Demonstrating prevention over time is a challenge. Appropriate MOPs/MOE provide leaders with tangible measures of efficacy and effectiveness and should remain constant even when leaders change
Different environments and subpopulations	Appropriate use of MOPs/MOE allows standardized and evidence-based programs to be implemented in multiple environments with different subpopulations. Tracking lessons learned allows for programs to be adapted to the target population and setting
Health literacy	Ensuring the program material targets, the appropriate health literacy level of the population will enhance program efficacy and effectiveness

A: Adoption by Target Settings, Institution, and Staff

Adoption refers to the proportion of individuals or organizations that adopt the injury prevention program and the determination of associated barriers to *adoption* by nonparticipating individuals and organizations [7, 8]. To address low *adoption* rates, leaders developing injury prevention, health promotion, and performance optimization programs should consider many barriers that could negatively influence *adoption* of a new and innovative program. Injury prevention, health promotion, or performance optimization programs should be designed so they can be easily adopted across a variety of military settings (e.g., Active Duty, Reserve, and National Guard). To maximize *adoption*, a program should be adaptable to meet the specific needs of the target audience (special operations, combat units, combat support units, and combat service support units). Additionally, the program has to be adaptable in a variety of climates: hot, cold, humid as well as at higher altitudes. Can the program be adopted by high-risk populations in the typical constrained resource setting? Do the units have organic assets (e.g., medical staff, master fitness trainers, master resiliency trainers) to ensure the program is adopted properly? Is the program aligned with other programs so that it can be easily adapted and is synergistic with other demands and priorities? To maximize *adoption*, the program development team has to plan for the program's costs and the level of resources and expertise required [3]. Padua et al. describe the following steps to help improve *adoption* of injury prevention programs: (1) establish support for the program and have key stakeholders identify barriers to implementation and strategies to overcome those barriers, (2) develop programs that apply the best available evidence that incorporates strategies to overcome the identified barriers, (3) ensure competency and self-efficacy of the trainers that will lead the program, (4) provide routine feedback and coaching to the trainers to ensure

program fidelity, and (5) reduce feedback (both quantity and frequency) to the trainers based on their ability to effectively implement the program [35].

Strategic-Level Barriers

Ideally, leaders at the strategic level would develop and promote evidence-based injury prevention, health promotion, and performance optimization programs. As previously discussed, one of the historical problems associated with translating evidence-based injury prevention programs into practice is that research often focuses on program *efficacy* [3]. *Efficacy* studies tend to assess injury prevention programs in a singular setting to reduce variability. These studies typically utilize more resources (financial, personnel, and expertise) than will be available when the injury prevention program is implemented with a larger audience. Although it is important for initial studies to focus on internal validity to demonstrate the *efficacy* of the injury prevention program, they rarely address the needs of a broader audience which can limit *adoption*. *Effectiveness* studies that address how to implement the program in multiple settings and how it can be adapted to meet the needs of the different subpopulations are typically lacking [35].

One of the key elements of a program is to train strategic leaders to consider how to preserve the evidence-based elements of a program while also allowing the operational and tactical leaders the ability to adapt specific elements to maximize *adoption* for their environment and setting [3]. Therefore, a key planning factor that should be addressed by strategic leaders is to develop injury prevention, health promotion, and performance optimization programs that are both standardized and adaptable to meet the needs of the various organizations and the different risk levels of the target audience. For example, the Ranger Athlete Warrior (RAW) program was created to optimize human performance while minimizing injury risk [36]. The program had many standardized components that focused on the type of exercise (e.g., cardiovascular, strength, endurance, power, agility, balance, etc.) as well as proper dose (frequency, intensity). However, the program also provided flexibility in how it was executed at the tactical level by allowing the individual physical training leaders to select which exercises under the main categories would be performed tailored to the unit's needs. To maximize *adoption*, strategic leaders should develop policy and doctrine that allows units to tailor the program based on the unit's mission and needs while maintaining consistency in core features to ensure program *effectiveness and adoption*.

Operational-Level Barriers

Glasgow et al. describes organizational impact (OI) of an injury prevention program based on both successful *adoption* and *implementation* of the program [3]. Therefore, operational leaders should focus on the organization barriers to successful *adoption* and *implementation* (discussed in the next section) of injury prevention programs to maximize organizational impact. The key variables for successful *adoption* often include: key leader buy-in, time, financial support, and staffing. A plan that includes strategies to de-conflict competing priorities can help optimize *adoption* [21].

Once a program is implemented, operational leaders should measure the *adoption* of the program to determine organizational barriers that may limit the success of the program. Operational leaders should assess the willingness of stakeholders from multiple settings to successfully adapt and adopt the program. Key variables to measure include representativeness of settings, participation rates for organizations, and reasons for declining participation (staffing, resources, time, etc.). Identification of an accurate and appropriate denominator for *adoption* is essential to track the program *adoption* [3]. Lessons learned from organizations that have successfully adopted the program can be utilized to enhance overall *adoption* of the program across other units within the organization.

Tactical-Level Barriers

At the tactical level, *adoption* is tracked as the number of individuals that adopt the program based on the number of potential adoptees [8]. Determining if peer opinion leaders adopt the program may serve as an early indicator to a program’s success. To maximize *adoption*, the program should be easily integrated in the daily schedule while addressing competing priorities on the service member’s time. The training delivered should be integrated with prior knowledge and perceptions to optimize *adoption*. Successful *adoption* requires that the program to be customizable based on the individual’s risk or performance level. This can be as simple as conducting unit physical training based on ability groups or as complex as tailoring programs based on specific risk levels (green = low risk to red = high risk) [18].

Technology can be leveraged to address many of the barriers to *adoption* of injury prevention, health promotion, and performance optimization programs to assist in creating and sustaining changes for health (Table 16.3). For example, web-based resources can be provided to help educate and inform service members. Applications (both web-based and smartphone) can be used as a digital diary to track key parameters (i.e., nutrition and fluid intake). Biosensors can be utilized to automatically track physical activity and sleep. The combination of biosensors and mobile applications can be utilized to improve self-awareness, motivate individuals, and foster a competitive drive through their social media components, thus facilitating behavioral changes. Currently, over 50% of smartphone users search for health information on their phones and one out of five have at least one health app on their phone [37]. Podcasts, reading daily

Table 16.3 Utilization of technology to overcome barriers to health

Barrier to health	Leverage technology
Knowledge of how to track calories in, calories out, and sleep quantity	Digital food, exercise, and sleep diaries
	Easy access to online health resources
Planning a program	Automated meal and exercise planners
Goals and tracking progress	Automatic tracking, graphs and trend lines, and daily reminders about goal obtainment
Time	Automated biosensors to collect data, databases that automate tracking
Social support	Social networks, groups, and competitions
Incentives	Points, badges, competition, and awards

health-related tweets, and posting daily updates on social networks result in greater weight loss. Specifically, participants had a 0.5% weight loss for every 10 daily tweets they posted about their diet and weight loss [38]. Exercises promoted through social networks resulted in increased participation in core strengthening (72% participated for 1 month and 47% participated for 2 months) [39]. In general, mobile app users over a 6-month period had increased physical activity, decreased caloric intake, and decreased weight compared to nonusers [40–42]. It is still important to remember that although technology can be helpful in addressing barriers to *adoption*, these programs may be limited by the technology and health literacy of the target population.

An integrated plan that identifies and mitigates strategic, operational, and tactical barriers to *adoption* can be utilized to optimize adoption of injury prevention, health promotion, and performance optimization programs. A summary of potential barriers and solutions to enhance *adoption* of injury prevention programs is provided in Table 16.4.

Table 16.4 Potential barriers and solutions to enhance *adoption* for the target population in military injury prevention programs [3, 8, 21, 43, 44]

Potential barrier	Potential solutions
Culture	Programs should be standardized to address key evidence-based injury prevention, health promotion, and performance optimization principles. The execution should be adaptable to the culture of the different organizations and units to maximize adoption
Motivation	The injury prevention, health promotion, or performance optimization program should generate leader and user buy-in. Linking these programs to performance and unit readiness could enhance motivation and help maximize adoption. The program should address motivational issues that may limit adoption at the organization and individual level
Leader knowledge and support of the program	Prior to program implementation, leaders should be provided professional development on both the need and effectiveness of the injury prevention, health promotion, and performance optimization program. Early adoption of the program by key leaders will help maximize adoption
Modularized/customizable	Design training programs to be adaptable in multiple settings and not specific to a particular setting
User and organizational needs	Programs that are designed to be run by the organization and not “imposed” from the outside tend to be more successful. Programs should address prevailing practices, incentives, or regulations that oppose innovation and change
Cost	Programs should be developed and resourced based on the known fiscal restraints
Time	Programs should address competing demands on time and find ways to incorporate the training into existing schedules
Expertise required	Training modules should be developed and packaged based on the expertise that organically exists in the unit to optimize adoption. Training manuals should be developed that allows the unit leaders to easily adopt the program
Difficult to learn	The material should be appropriate for the audience. See section on health literacy. This material should be pilot tested to ensure the training material accounts for needs of the end user

I: Implementation (Consistency and Costs of Delivery of Intervention)

The *implementation* of injury prevention, health promotion, or performance optimization programs can be crucial to a program's success. The goal is to ensure that the program is delivered consistently and, as intended, [8] to the target audience across the enterprise. This can be challenging in a single location and exponentially difficult when that enterprise includes multiple locations with various resources and crosses international borders—all of which are common challenges in the Active Duty, Reserve, and National Guard components of the military. Any program that is delivered across the US military will face the potential of local modifications to the program that may alter the effects of the program as well as the outcomes. Effective implementation requires standardized protocols or intervention recommendations [45]. However, military leaders are accustomed to autonomy [46] in their units and may modify key elements of one of these programs and inadvertently introduce variability that decreases the program's *effectiveness*. Proper *implementation* should control for variability of key elements of a program to ensure consistency in delivery and desired outcome. This variability may be introduced at various levels of program *implementation* from strategic to tactical and each has its own challenges with proper program *implementation*.

Strategic-Level Barriers

In any large organization, the challenge with implementing an injury prevention, health promotion, or performance optimization program is having a program that is vast and variable enough to affect all target populations. The US military is no different. Each service within the US Armed Forces (Army, Air Force, Navy, Marines, and Coast Guard) should maintain a readiness state that necessitates mitigation of musculoskeletal injuries. Each is interested in not only reducing injury but simultaneously improving functional performance. The variance, however, in the services—from their corporate-level leadership to their diversified strategic missions—makes establishment of a single military program that will equally impact all US service members unlikely.

Even within single service, developing injury prevention programs that encompass the entire organization is challenging. The US Army is a case in point. The US Army has three components (Active Duty, Reserve, and National Guard); each is organized based on multiple occupational specialties and these specialties are assigned to units that are designated for direct combat, combat support (fire and operational assistance to combat arms), or combat service support (logistical assistance to combat arms) missions. Just as the roles of these occupations and designations vary—from infantry to cook—so too do the functional requirements of each—from analyzing intelligence data in an office to performing special operations missions on the battlefield. The DoD is challenged as it endeavors to implement programs that are applicable across all of the occupations. Programs need to be standardized across the service and also need to have enough flexibility

to be modifiable to target the unique facets and risks inherent to this broad range of differing occupations and specialties.

As each of the services in the US Armed Forces strives for standardization in their injury prevention, health promotion, and performance optimization programs, they must factor in the cost to implement these programs in relation to the benefits realized—in dollars and manpower. As the program is developed at the strategic level, each service should determine the overall cost for any equipment needs as well as facilities and supplies. For a cost-conscious military, programs with even modest equipment or supply requirements may get shelved. Additionally, as programs are developed, the services should take into consideration the training requirements to field a new program across the entire organization. They should ask themselves whether the program can be implemented with existing manpower or if they will require additional personnel to implement, train, and monitor the programs. Leaders should also consider the cost-benefit analysis and may end up weighing programs with potentially greater outcomes but greater cost against programs with less cost but potentially less injury prevention impact.

Operational-Level Barriers

At the operational level, units often combine injury prevention and performance optimization programs. Unless the services provide strategic-level directives, most operational-level programs are determined by commanders of elements sized from a few hundred to a few thousand service members. These programs may be research- and outcome-based but may just as likely be based on the current popular programs—with or without data to support their impact on readiness, injury prevention, and individual/unit performance. As new commanders transition into the unit, new programs may be instituted—often before existing programs have been fully evaluated for their *effectiveness* at reducing injury or improving performance. This cyclic *implementation* of programs makes it difficult for both strategic- and operational-level leaders to track successful program outcomes and make recommendations on best practices for their subordinate units.

Tracking the effects of injury prevention, health promotion, and performance optimization programs is crucial. As with any program designed to effect change, it is important to start with good baseline data. It is often tempting to implement new programs in a rapid manner without first fully determining the current state. Leaders must know the current medical readiness rates of their units and understand to what extent that is driven by musculoskeletal injury. Understanding the injury rates of their units will help leaders and implementers of the injury prevention, health promotion, or performance optimization programs to select the proper tracking metrics. The metrics that are selected may vary from unit to unit at the operational level—even with the same type of program implemented. As discussed at the strategic level, variances in the units and their missions may necessitate monitoring different injury and performance metrics to determine medical readiness for that unit. Regardless of the metrics chosen, they must be able to be tracked by all involved units, they must be associated with the injury prevention and human performance

optimization program, and they must tell the story to the unit leaders. An injury prevention program that is monitored with metrics that demonstrate improvements in medical readiness is much more likely to get buy-in and support from the unit leadership, thereby ensuring its continued use. Likewise, programs that take advantage of new or existing technology to track progress are more likely to be implemented.

Members of the US Armed Forces seek medical care in military treatment facilities that require electronic documentation. This potentially provides a wealth of information for monitoring injury at the individual and unit levels. This documentation could provide date of injury, type of injury, method of injury, and length of injury. The challenge is that obtaining the information is not an easy process, and it relies on medical professionals to provide the information in the proper data fields in the electronic document.

Finally, units at the operational level are challenged with proper *implementation* of programs directed from the strategic level. Service-wide injury prevention, health promotion, and performance optimization programs require standardization in their *implementation*. Most programs will be accompanied by policy guidance and an operations order with detailed instructions. The operational units then develop their standard procedures for implementing the directed programs. With the variation in the types of units, as discussed previously, and the autonomy in running training at the unit level, there exists the possibility of inconsistency in the *effectiveness* of programs across the organization. This potential for variance can be somewhat mitigated by ensuring that a strategic directive includes specific training packages, curriculum, and even training teams to guide the units as they implement the program.

Tactical-Level Barriers

At the tactical level, injury prevention, health promotion, and performance optimization programs come face-to-face with the service member and the smaller elements of the organization. The challenge for leaders at this level is to secure the “buy-in” from their individual service members and teams. This can be particularly onerous when the program replaces or vies for resources from a more mainstream trending program. A useful tactic in this environment is to take advantage of individual and team-level competition. As with athletes (individual and team), service members are often motivated by the competition against their fellow service members and the other elements in the unit. Understanding this competitive nature can be instrumental in implementing a successful program. Broadly communicating the program successes can ignite greater acceptance during *implementation*. Likewise, the element leaders may be more willing to implement new programs when the medical readiness rates and successes of their sister units are known.

Another challenge to the successful *implementation* of an injury prevention program is the propensity of service members to mask or hide musculoskeletal injuries. Service members often will not disclose an injury to their leaders or to their medical staff if they feel that this will keep them out of training, exercises, or missions. With a mild injury, this becomes even more likely as the service member “toughs it out” in the belief that their actions will minimize the impact. Musculoskeletal injuries that are

left untreated in the early stages often worsen and may result in even greater negative consequences on individual and unit medical readiness [47–50]. As new programs are implemented and greater scrutiny is placed on musculoskeletal injury, service members may be even more inclined to “hide” their injuries and avoid the attention that it can draw. Those implementing new injury prevention programs should be attuned to these nuances in their service members and should work to mitigate the potential stigma associated with reporting new or mild musculoskeletal injuries.

Finally, a challenge with injury prevention and human performance optimization programs at the small-unit level can be with the individuals selected to implement the program. The small elements in the military organization have few individuals and many missions. In that scenario, the service member selected to implement this type of program often has many responsibilities, and this program *implementation* becomes merely an additional duty in their portfolio. Injury prevention, in this environment, is forced to compete with the myriad of demands on the service member selected to implement the program at the small-unit level. There is the potential for the injury prevention program to slide to the bottom of the priority scale or to be given little attention or effort at that level. When that occurs, the program risks incorrect *implementation*, failure to be fully embraced, and inadequacy of exertion to ensure the program’s potential for success. Leadership buy-in and making program implementation a leadership priority can often overcome some of these barriers to *implementation*.

An integrated plan that incorporates strategic, operational, and tactical barriers to *implementation* can be utilized to optimize injury prevention programs. A summary of potential barriers and solutions to enhance *implementation* of injury prevention programs is provided in Table 16.5.

Table 16.5 Potential barriers and solutions to enhance *implementation* for the target population in military injury prevention programs [21]

Potential barrier	Potential solutions
Programs that work for multiple occupational specialties and units	Develop programs with input from various units/specialties and tested in multiple units
Program cost	Creative collaboration to develop programs that use minimal equipment and that can be implemented in multiple locations (including overseas)
No consistent program across the service	Standardize programs at the service level ensuring that senior-level leadership endorses. Develop compliance metrics as part of the implementation
Programs implemented without metrics success	Meet with commanders, determine their needs for readiness, and seek their assistance in developing metrics tailored to their needs
Inconsistency in program implementation across units	Develop training package, educational materials, and metric tracking before program is implemented—then push this package during implementation
Getting “buy-in” at the small unit/element level	Institute programs that can be compared against other small units for medical readiness and program success
Service members hide or do not divulge full details of injury in order to stay “on mission”	Work with the service member and unit to safely maximize their participation in training/missions and communicate positive effects of program leading to mission readiness

M: Maintenance of Intervention Effects in Individuals and Settings

Successfully maintaining meaningful injury prevention programs requires ongoing and critical long-term assessment and the integration of best practices on the strategic, operational, and tactical levels. Specifically, the program *maintenance* provides the DoD and unit leaders the opportunity to assess if current injury prevention programs and policies are integrated into routine organizational practice, resulting in individual behavior change. Additionally, the *maintenance* phase allows unit leaders and individuals to evaluate the long-term (6 or more months) effects of injury prevention interventions [4], thus allowing for ongoing and needed modifications that may facilitate ongoing program success. Despite its critical importance to long-term analysis and outcomes, recent evidence suggests that the *maintenance* phase for health promotion and injury prevention programs is often not assessed, which presents unique challenges at the institutional and individual level [4]. The following sections and Table 16.6 address lessons learned from previous literature as well as outline potential barriers and solutions to the military-specific injury prevention program *maintenance* at the strategic, operational, and tactical levels.

Strategic-Level Barriers

Strategic leaders in the civilian and military communities face similar concerns for *maintenance* of injury prevention and health promotion policies. Critical analysis of the RE-AIM model suggests that program longevity is often strategically compromised by an inability to track and report the long-term (6 months or greater) program *adoption*. In particular, literature supports that less than half (41.2%) of health promotion and injury prevention programs track the long-term (6 months or greater) program *maintenance* [4]. Although the structure of the DoD provides a framework for joint integration of best practices for injury prevention interventions, the translation from policy to system-wide *adoption* is not guaranteed, and the DoD should continue to track and address long-term injury prevention program utilization and associated barriers to program participation. The Unit Status Report provides a potential system-wide mechanism for tracking on-duty injury prevention program utilization and associated barriers. The annual Periodic Health Assessment (PHA) also provides the potential to assess injury prevention compliance (e.g., wearing a helmet when biking, exercise routine outside of formal physical training sessions) and satisfaction with both on- and off-duty injury prevention initiatives.

Program *maintenance* at the strategic level is compromised by a lack and diversity of standardized outcome metrics. A systematic review by Gaglio et al. [4] recently identified that only 32.6% of RE-AIM health promotion and injury prevention programs employed multiple long-term (6 months or greater) program

Table 16.6 Potential barriers and solutions to enhance *maintenance* for the target population in military injury prevention programs [21]

Potential barrier	Potential solutions
Inability to track program utilization, attrition, and compliance	(1) Standardized reporting for injury prevention program utilization via the unit status report and (2) PHA for on- and off-duty program compliance
Primary outcome measure only focused on injury rates and severity	Inclusion of broad metrics that integrate readiness, optimal human performance, reduced long-term disability, patient satisfaction, and quality of life (life space)
Lack of acceptable outcomes and clarity on reportable items	(1) Collaboration between strategic leaders and subject matter experts and best evidence to define anticipated and acceptable injury rates and (2) agreement on reportable high-risk musculoskeletal injuries
Unit resources (time, money, and expertise)	Collaboration between unit, military treatment facility, and garrison resources and expertise to maximize best practice for injury prevention initiatives
Resources and expertise for ongoing critical assessment and modifications of injury prevention programs at the unit level	(1) Comparison with The Armed Forces Health Surveillance Service Center database and (2) ongoing injury prevention council at the installation level that address installation and unit level needs and program modification
Balance between optimal performance and injury prevention	(1) Addition of outcome metrics to meet specific unit demands, (2) assessment of both performance and injury prevention metrics
Occupational and individual variance	(1) Potential need to address individual/occupation variance in future models and (2) define characteristics for optimal MOS performance and acceptable injury risk
Behavior change: Internal barriers Interpersonal barriers Environmental barriers	(1) Identify barriers to individual behavior change, (2) leverage peers and technology to provide reminders, (3) increase education time and various research to enhance learning, (4) identify relationship impeding program completion, and (5) provide equipment and transportation to assist environmental needs

MOS Military Occupational Specialty, *PHA* Periodic Health Assessment

outcome metrics. Investigators specifically noted that the *maintenance* phase of policies and programs did not include broad metric analysis of items such as unintended outcomes, quality of life, attrition, alignment to organization mission, and sustainability [4]. Leaders within the DoD injury prevention community have also recently emphasized the importance of diverse metrics, in addition to typical injury frequency and severity data, for prioritizing and assessing injury prevention programs [4, 51]. Inclusion of multiple metrics that evaluate readiness, optimal human performance, long-term disability, unintended outcomes, participant

satisfaction, quality of life, program costs, and potential cost savings overtime would provide policy makers and strategic leaders with additional data for program analysis. Furthermore, focusing on outcome metrics that are also of importance to operational and tactical-level leaders is likely to enhance the program *adoption* and *maintenance* at these levels.

Standardization of required injury prevention outcome metrics that are reported on the corporate and unit level are needed and require continued collaboration between military medicine, civilian partners, and unit leaders. Senior leaders and subject matter experts in the DoD should also continue to answer the following challenging but critical questions: (1) What are the top strategic injury prevention objectives and initiatives, (2) what is an acceptable musculoskeletal injury rate across the services and within each branch, (3) what level of disability is acceptable for specific body regions and musculoskeletal health conditions, and (4) what specific metrics and high-risk conditions are reportable to the DoD? Without this level of detail, unit leaders and service members lack the specific guidance and metrics required to assess unit training and the impact of health performance optimization and injury prevention initiatives.

Operational-Level Barriers

Effective injury prevention program *maintenance* at the operational level requires an ongoing commitment and integration of unit, medical treatment facility, and garrison resources in the form of time, equipment, space, money, and personnel. The ongoing *maintenance* of a well-balanced injury prevention program would ideally require minimal resources outside of the unit. Additionally, unit leaders and medical personnel assigned to the Brigade Surgeon Cell or service equivalent would collectively agree on the resources needed to maintain current injury prevention programs and ongoing long-term outcome assessments. Unit commanders and the Brigade Surgeon could also identify subject matter experts who can supervise training, data collection sessions, data analysis, and data reporting for the Unit Status Report. Garrison resources to include gym space, equipment, and personnel (installation safety officer) may also be required at specific sites and may ultimately assist in integration of best practices and data collection across the installation. Unit commanders should also conduct periodic injury prevention program assessment with subject matter experts from the unit (e.g., brigade surgeon, brigade physical therapist) and local medical treatment facility (chief of preventive medicine, chief of physical therapy, chief of resource management). The objectives of these meetings are to assess program outcomes (e.g., injury rates, injury types, health-care utilization, physical readiness, and disability data), address barriers in program compliance, formulate strategies for high-risk populations, and integrate resources across the installation.

The operational needs and success of injury prevention programs are ultimately assessed by unit commanders and medical personnel assigned to the unit.

Although strategic guidance is provided for injury prevention interventions and specific reportable metrics are required by the DoD, it is ultimately the local commander and medical team that determine the health, welfare, and readiness of their respective unit. The importance of actionable data at this level cannot be overstated. Unit leaders and medical personnel should collectively and critically assess their unit injury rates and performance on injury prevention and physical performance screening measures. The Armed Forces Health Surveillance Service Center website (<http://www.afhsc.mil/injuryReports>) provides health professionals and leaders with specific metrics related to trends in injury incidence, causes of serious injuries, and injuries per body regions for various military installations and services (Army, Navy, Marine Corps, and Air Force).

Unit commanders are consistently required to balance the risk of injury with the need to train service members to obtain specific physical performance characteristics for successful mission completion. Previous research supports that injury rates may vary depending on the unit's specific mission and level of training [52, 53]. Commanders may identify a need for inclusion of unit-specific physical performance metrics beyond the standard unit physical fitness test. The RAW Fitness Assessment is one example of a tailored long-term outcome metric used to assess physical performance and mission capability in a specific subset of Army soldiers. Unit leaders and medical providers should carefully consider the need for additional metrics, and if items are employed, they should exhibit sound psychometric properties and apply to the specific population under investigation.

Tactical-Level Barriers

Injury prevention program *maintenance* ultimately requires individual behavior change and periodic long-term assessment and modification of health behaviors. Similar to the variability in performance observed among different athletes [54], service members' physical performance varies greatly depending on occupational demands and environmentally related factors [19, 20, 55]. In fact, research by Hollander and Bell suggests that military occupations should be matched to the physical demands of the job [55]. Unfortunately, there are not always clear cut definitions or specific physical demands that are defined for every military occupation. Additional research examining injury prediction and physical performance for specific military occupations appears to be warranted and potentially may provide more robust injury prediction models, screening requirements and tailored injury prevention interventions.

Tactical injury prevention *maintenance* is also closely tied to individual behavior change. Potential individual barriers to accepting health promotion and disease management change include internal factors, interpersonal relationships, and environmental factors [56]. Internal factors such as motivation, lack of time, lack of knowledge, and self-efficacy are all related to the inability to change health behavior and may ultimately interfere with acceptance of injury prevention interventions

such as corrective exercises [56, 57]. Interpersonal relationships may also distract participants from successful integration of injury prevention interventions. Finally, environmental factors such as inadequate equipment or space may limit injury prevention compliance. Potential solutions to facing internal, interpersonal, and environmental barriers include more personalized or individualized time for education and program completion, collaborative partnerships (e.g., encouragement from a battle buddy), interactive reminders in the form of application reminders or text messages, or assistance with transportation or equipment needs for environmental access to equipment and space [56–58].

Conclusion

Musculoskeletal injuries within the US military present a significant concern due to their effect on individual and unit readiness as well as their adverse impact on performance. Preventing these injuries, where possible, is an objective across all services in the DoD. Developing, implementing, and tracking injury prediction programs are a complex undertaking in an organization that spans multiple occupations, geographic areas, missions, capabilities, and readiness levels. The RE-AIM model introduced by Glasgow provides an effective evaluative approach to addressing the barriers to public health programs including injury prevention. The RE-AIM model focuses on the five dimensions of *reach, efficacy/effectiveness, adoption, implementation, and maintenance*. The RE-AIM model provides a framework for the development and evaluation of injury prevention programs. Failure to properly evaluate an injury prevention program and the barriers that it faces during implementation can lead to failure of the program and a loss of valuable resources in the effort. We have used the RE-AIM model to examine injury prevention in the military with a focus on the barriers that all services face when establishing these programs. Additionally, we have looked at each dimension from the perspective of three organizational levels—strategic, operational, and tactical. Hopefully the information contained in this chapter will provide a framework and strategies for developing and implementing more effective injury prevention efforts to mitigate the burden of musculoskeletal injuries in the military.

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References

1. Koh HK. A 2020 vision for healthy people. *N Engl J Med*. 2010;362(18):1653–6.
2. Fielding J, Kumanyika S. Recommendations for the concepts and form of Healthy People 2020. *Am J Prev Med*. 2009;37(3):255–7.
3. Glasgow RE, Lichtenstein E, Marcus AC. Why don't we see more translation of health promotion research to practice? Rethinking the efficacy-to-effectiveness transition. *Am J Public Health*. 2003;93(8):1261–7.
4. Gaglio B, Shoup JA, Glasgow RE. The RE-AIM framework: a systematic review of use over time. *Am J Public Health*. 2013;103(6):e38–e46.
5. Nindl B, et al. Strategies for optimizing physical readiness and preventing musculoskeletal injury in the 21st Century. *US Army Medical Department Journal*, 2013: p. 5–13.
6. Green LW. From research to “best practices” in other settings and populations. *Am J Health Behav*. 2001;25(3):165–78.
7. Akers JD, Estabrooks PA, Davy BM. Translational research: bridging the gap between long-term weight loss maintenance research and practice. *J Am Diet Assoc*. 2010;110(10):1511–22, 1522 e1–3.
8. Glasgow RE, Vogt TM, Boles SM. Evaluating the public health impact of health promotion interventions: the RE-AIM framework. *Am J Public Health*. 1999;89(9):1322–7.
9. Finch C. A new framework for research leading to sports injury prevention. *J Sci Med Sport*. 2006;9(1–2):3–9 (discussion 10).
10. Littman AJ, et al. Weight change following US military service. *Int J Obes (Lond)*. 2013;37(2):244–53.
11. Hoerster KD, et al. Health and health behavior differences: U.S. Military, veteran, and civilian men. *Am J Prev Med*. 2012;43(5):483–9.
12. Yancosek KE, Roy T, Erickson M. Rehabilitation programs for musculoskeletal injuries in military personnel. *Curr Opin Rheumatol*. 2012;24(2):232–6.
13. Ross J, Weill P, Robertson D. Define your operating model: designing a foundation for execution, in *Harvard Business Press Chapters*. 2006, Harvard Business Review: Harvard. p. 1–24.
14. Lisman P, et al. Functional movement screen and aerobic fitness predict injuries in military training. *Med Sci Sports Exerc*. 2013;45(4):636–43.
15. Gribble PA, Hertel J, Plisky P. Using the Star Excursion Balance Test to assess dynamic postural-control deficits and outcomes in lower extremity injury: a literature and systematic review. *J Athl Train*. 2012;47(3):339–57.
16. Plisky PJ, et al. Star excursion balance test as a predictor of lower extremity injury in high school basketball players. *J Orthop Sports Phys Ther*. 2006;36(12):911–9.
17. Kiesel K, Plisky PJ, Voight ML. Can serious injury in professional football be predicted by a preseason functional movement screen? *N Am J Sports Phys Ther*. 2007;2(3):147–58.
18. Teyhen DS, et al., Automation to improve efficiency of field expedient injury prediction screening. *J Strength Cond Res*. 2012;26(Suppl 2):61–72.
19. Hill OT, et al. Risk factors for soft tissue knee injuries in active duty U.S. Army soldiers, 2000–2005. *Mil Med*. 2013;178(6):676–82.
20. Roy TC, et al. Risk factors for musculoskeletal injuries for soldiers deployed to Afghanistan. *Aviat Space Environ Med*. 2012;83(11):1060–6.
21. Jenkinson KA, Naughton G, Benson AC. The GLAMA (Girls! Lead! Achieve! Mentor! Activate!) physical activity and peer leadership intervention pilot project: a process evaluation using the RE-AIM framework. *BMC Public Health*. 2012;12:55.
22. Abrams DB, et al. Integrating individual and public health perspectives for treatment of tobacco dependence under managed health care: a combined stepped-care and matching model. *Ann Behav Med*. 1996;18(4):290–304.
23. Bloom JR, Monterossa S. Hypertension labeling and sense of well-being. *Am J Public Health*. 1981;71(11):1228–32.

24. Downs WR, Robertson JF, Harrison LR. Control theory, labeling theory, and the delivery of services for drug abuse to adolescents. *Adolescence*. 1997;32(125):1–24.
25. Knapik JJ, et al. A prospective investigation of injury incidence and injury risk factors among Army recruits in military police training. *BMC Musculoskelet Disord*. 2013;14:32.
26. dela Cruz GG Knapik JJ Birk MG. Evaluation of mouthguards for the prevention of orofacial injuries during United States Army basic military training. *Dent Traumatol*. 2008;24(1):86–90.
27. Knapik JJ, et al. Injury and fitness outcomes during implementation of physical readiness training. *Int J Sports Med*. 2003;24(5):372–81.
28. Bahr R, Holme I. Risk factors for sports injuries—a methodological approach. *Br J Sports Med*. 2003;37(5):384–92.
29. Edmonds JN, Vinson DC. Three measures of sleep, sleepiness, and sleep deprivation and the risk of injury: a case-control and case-crossover study. *J Am Board Fam Med*. 2007;20(1):16–22.
30. Soligard T, et al. Compliance with a comprehensive warm-up programme to prevent injuries in youth football. *Br J Sports Med*. 2010;44(11):787–93.
31. Emery CA, Meeuwisse WH. The effectiveness of a neuromuscular prevention strategy to reduce injuries in youth soccer: a cluster-randomised controlled trial. *Br J Sports Med*. 2010;44(8):555–62.
32. Ortiz A, et al. Effectiveness of a 6-week injury prevention program on kinematics and kinetic variables in adolescent female soccer players: a pilot study. *PR Health Sci J*. 2010;29(1):40–8.
33. Ratzan S, Parker R. Health literacy, in national library of medicine current bibliographies in medicine. In: Seldon C, et al., Editors. National institutes of health, U.S. Washington D.C.: Department of Health and Human Services; 2000.
34. Kutner M, et al. The health literacy of America's adults: Results from the 2003 National Assessment of Adult Literacy. NCES 2006–483. National Center for Education Statistics; 2006. p. 1–76.
35. Padua D, et al. Seven steps for developing and implementing a preventive training program: lessons learned from JUMP-ACL and beyond. *Clin Sports Med*. 2014;33(4):615–32.
36. McMillian D. Ranger-Athlete-Warrior: A systematic approach to conditioning. *Infantry*; 2007;96(3):5–8.
37. Fox S, Duggan M. Mobile Health 2012: Pew Research Center's Internet and American Life Project. Pew Research Center. 2012;1–29.
38. Turner-McGrievy GM, et al. Comparison of traditional versus mobile app self-monitoring of physical activity and dietary intake among overweight adults participating in an mHealth weight loss program. *J Am Med Inform Assoc*. 2013;20(3):513–8.
39. Pagoto SL, et al., The adoption and spread of a core-strengthening exercise through an online social network. *J Phys Act Health*. 2014;11(3):648–53.
40. Newton RL Jr, et al. Efficacy of a pilot Internet-based weight management program (H.E.A.L.T.H.) and longitudinal physical fitness data in Army Reserve soldiers. *J Diabetes Sci Technol*. 2011;5(5):1255–62.
41. Stewart T, et al. H.E.A.L.T.H.: efficacy of an internet/population-based behavioral weight management program for the U.S. Army. *J Diabetes Sci Technol*. 2011;5(1):178–87.
42. Stewart T, et al. Development of an internet/population-based weight management program for the U.S. Army. *J Diabetes Sci Technol*. 2008;2(1):116–26.
43. Hrysomallis C. Injury incidence, risk factors and prevention in Australian rules football. *Sports Med*. 2013;43(5):339–54.
44. Gianotti S, Hume PA, Tunstall H. Efficacy of injury prevention related coach education within netball and soccer. *J Sci Med Sport*. 2010;13(1):32–5.
45. Glasgow RE, et al. Evaluating the impact of health promotion programs: using the RE-AIM framework to form summary measures for decision making involving complex issues. *Health Educ Res*. 2006;21(5):688–94.
46. Huntington S. The soldier and the State. Cambridge: Harvard University Press;1957.
47. Buckwalter JA. Articular cartilage injuries. *Clin Orthop Relat Res*. 2002;402:21–37.

48. Ballas MT, Tytko J, Mannarino F. Commonly missed orthopedic problems. *Am Fam Physician*. 1998;57(2):267–74.
49. Heckman DS, Gluck GS, Parekh SG. Tendon disorders of the foot and ankle, part 2: achilles tendon disorders. *Am J Sports Med*. 2009;37(6):1223–34.
50. Heckman DS, Gluck GS, Parekh SG. Tendon disorders of the foot and ankle, part 1: peroneal tendon disorders. *Am J Sports Med*. 2009;37(3):614–25.
51. Canham-Chervak M, et al. A systematic process to prioritize prevention activities sustaining progress toward the reduction of military injuries. *Am J Prev Med*. 2010;38(1 Suppl):11–8.
52. Jones BH, Knapik JJ. Physical training and exercise-related injuries. Surveillance, research and injury prevention in military populations. *Sports Med*. 1999;27(2):111–25.
53. Kotwal RS, et al. Army Ranger casualty, attrition, and surgery rates for airborne operations in Afghanistan and Iraq. *Aviat Space Environ Med*. 2004;75(10):833–40.
54. Hrysomallis C, McLaughlin P, Goodman C. Balance and injury in elite Australian footballers. *Int J Sports Med*. 2007;28(10):844–7.
55. Hollander IE, Bell NS. Physically demanding jobs and occupational injury and disability in the U.S. Army. *Mil Med*. 2010;175(10):705–12.
56. Timmerman GM. Addressing barriers to health promotion in underserved women. *Fam Community Health*. 2007;30(1 Suppl):34–42.
57. Ory MG, et al. The science of sustaining health behavior change: the health maintenance consortium. *Am J Health Behav*. 2010;34(6):647–59.
58. Lattimore D, et al. Understanding the challenges encountered and adaptations made by community organizations in translation of evidence-based behavior change physical activity interventions: a qualitative study. *Am J Health Promot*. 2010;24(6):427–34.

Index

A

- Acromioclavicular (AC) joint injury, 111
- Active duty, 151, 157, 160–162, 222
- Acute knee injuries, incidence of, 156
- Ankle,
 - bracing, 276, 277
 - athletic and training activities, 276
 - parachuting, 277
 - sprains, 179–185
 - epidemiology, 180
 - modifiable risk factors, 183–185
 - non-modifiable risk factors, 181–183
 - preventative measures, 185
- Anterior cruciate ligament (ACL), 5, 46, 93
 - chondral lesions, treatment of, 161
 - incidence of, 160
 - meniscal injury, 160
 - risk of, 160
- Athletic, 48, 149, 162, 183, 184
 - ankle bracing, 276

B

- Basic training, 166, 219, 220, 282
 - stress fractures, 74, 274, 280, 281

Blast, 14

- epidemiology of, 135

C

- Cervical spine,
 - clinical practice guidelines for, 241
 - epidemiology of, 233
 - history of, 244
 - non-traumatic, 235, 236
 - trauma, 236, 238
 - associated injuries, 238
 - injury, mechanism of, 236, 238

Combat, 4, 5, 12, 16, 19

- blast trauma, epidemiology of, 135
- burn injuries, 136
- cervical trauma, evaluation and management of, 240, 241, 244
- early management, 136, 138–140
 - combat trauma, late sequelae of, 140
 - upper extremity reconstruction, 138, 139
- nerve injuries, 136
- shoulder wounds, 108–111
- spine injury, history of, 231–233
- spine trauma, 224, 226
- Combat musculoskeletal wounds, 21
 - incidence rates of, 12–14
- Conceptual models, 262

D

- Disability,
 - chronic, 90
 - musculoskeletal injury, 155
 - orthopedic injuries, 106
 - osteoarthritis, 119, 164

E

- Epidemiology,
 - achilles injuries, 192, 193
 - ankle sprains, 180
 - blast trauma, 135
 - CECS, 178, 179
 - combat musculoskeletal wounds, 12–14
 - lisfranc injuries, 195
 - metatarsal fractures, 198, 200
 - metatarsal stress fractures, 201, 203, 205
 - military, 44
 - OLTs, 186, 187

- plantar fasciitis, 194, 195
- tibial stress fracture, 174, 176, 177
- US military, cervical spine injury in, 233
- Evidence-based decision-making
 - process, 258, 261, 265

F

- Femoral neck stress injuries (FNSIs), 69
- Femoroacetabular impingement (FAI), 149
- Fitness, 43, 44, 49, 54–56, 63, 65, 223, 283
- Foot,
 - achilles disorders, 190, 192, 193
 - lisfranc injuries, 195, 196
 - metatarsal fractures, 197, 200
 - metatarsal stress fracture, 200, 202, 203, 205
 - plantar fasciitis, 193–195
 - stress injuries, 74

G

- Glenohumeral joint instability, 113–115
- Greater trochanteric pain syndrome, 151

H

- Hand, 132, 134
 - fractures, 134
 - soft tissue injuries, 135
- Hip, 68
 - anatomy of, 148
 - extra-articular disorders, 151
 - incidence of, 6
 - intra-articular hip disorders, 148–150
 - FAI, 149
 - labral tears, 148, 149
 - osteoarthritis, 149, 150
 - stress fractures, 150
 - miscellaneous hip disorders, 151
- Human performance, 290, 294, 298, 301

I

- Implementation science, 262, 284
- Injury,
 - acute meniscal injury, 157, 158
 - bone stress, 65–68
 - assessment and diagnosis, 67, 68
 - risk factors for, 65–67
 - burn, 136
 - causes of, 214, 215
 - cervical spine injury, 233, 235, 236, 238
 - epidemiology, 233
 - non-traumatic, 235, 236
 - trauma, 236, 238
 - combat spine injury, history of, 231–233
 - extrinsic risk factors for, 47, 48

- femoral shaft stress, 72
- FNSIs, 69, 70
- foot stress, 74–76
 - calcaneal stress, 75, 76
 - metatarsal stress, 74, 75
 - tarsal stress, 76
- lower leg stress, 72–74
 - fibular stress injuries, 74
 - tibial stress injuries, 73, 74
- multiligamentous knee injury, 161, 162
- nerve, 136
- pelvic stress, 71, 72
- traumatic brain, 97
- Injury prediction, 294, 312
- Injury prevention, 39, 252–254, 293, 297, 298, 300, 301, 305, 310
 - initial entry training, 78–81
 - interventions, 262–265, 308, 311
 - military, essential elements for, 270–272
 - education, 271
 - leadership support, 272
 - research and program evaluation, 272
 - surveillance, 271
 - public health model, 256, 258, 259, 261
 - SMART centers, 278, 279
 - strategies, 272–277
 - ankle bracing, 276
 - military training, 277
 - risk factor identification, 273
 - training modification, 274–276
 - USMC, SMIP in, 279
- Injury surveillance, 44–46, 80, 255, 294

K

- Knee injury, 168
 - incidence of, 156

L

- Lumbago, 233
- Lumbar spine injuries, 213, 216, 218, 225

M

- Meniscus, 94, 157, 160
- Military, 5, 95, 105, 107, 112, 113, 127, 149, 163, 178, 216, 256
 - basic training, 219, 220
 - deployments, 28, 29, 36–39, 220, 221
 - early 1990s, 28, 29
 - NBI, burden and resource impact of, 36–38
 - preventing NBI, 39
 - MEPS, 62
 - occupation, 109
 - rank, 219

- reserves, 221
- service, branch of, 219
- sports injury surveillance and
 - epidemiology in, 44–46
- training, 48, 55, 66, 77, 147, 214, 254, 274

Military Entrance Processing Station (MEPS), 62, 63

Military readiness, 44, 62, 255, 297

Mortality, 17, 240

Musculoskeletal,

- imaging, 64
- injury, 3, 19, 20, 47, 49, 64, 269, 285
- prevalence of, 109, 155
- trauma, 12, 13, 20

N

Neck, 236, 241

- FNSIs, 69, 70

Non-battle injury (NBI), 26, 28

- causes of, 29
- contemporary military operations, 28
- military deployments, 36–39
 - burden and resource impact of, 36–38
 - preventing, 39

O

Occupational risk factors, 215

- artillery, 216
- aviators, 216, 217
- drivers, 218
- infantry, 215
- parachuting, 218

Occupations, 133

Osteochondral lesions of the talus (OLT), 185, 186

Overuse injury, 273, 276, 277

P

Policy change, 284, 285

R

Reach, efficacy/effectiveness, adoption, implementation, and maintenance (RE-AIM), 290, 312

- overview of, 291, 292

Rotator cuff disease, incidence of, 117

S

Scaphoid fractures, incidence of, 132

Shoulder injuries, 120

- AC joint sprains, 111
- clavicle fractures, 112, 113

Shoulder instability, 77, 78, 90

Spine, 92, 220, 224

Sport, 43, 44, 106, 259

- military, 44–54
 - extrinsic risk factors, 47, 48
 - intrinsic factors, 49–54
 - musculoskeletal injury, 47
- SMART centers, 278, 279
- USMC, SMIP in, 279

Sprain, 6, 132

- AC joint injury, 111
- ankle, 179, 180, 182–185
 - epidemiology, 180
 - modifiable risk factors, 183, 184
 - non-modifiable risk factors, 182, 183
 - preventative measures, 185

Stress fractures, 64, 76, 150

- basic training, 280, 281
- forearm, 127, 128
- metatarsal, 200, 202, 203
- non-modifiable risk factors for, 65
- tibial, 173, 174, 176, 177

Stress injuries, incidence of, 75

T

Thoracic, 214, 220

Trauma,

- cervical, 236, 238
 - associated injuries, 238
 - injury, mechanism of, 236, 238
- combat, 135–139, 141
 - blast trauma, epidemiology of, 135
 - burn injuries, 136
 - early management, 136–139, 141
 - nerve injuries, 136
- spine, 224, 225

U

Upper extremity, 125, 141

- amputations, 91, 92
- limb salvage, 92
- reconstruction, 138, 139
- rotator cuff, 91
- shoulder instability, 90, 91

V

Veteran, 97, 119

Predicting Neck Pain in Royal Australian Air Force Fighter Pilots

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ABSTRACT Objective: Fighter pilots frequently report neck pain and injury, and although risk factors have been suggested, the relationships between risk factors and neck pain have not been quantified. The aim of this study was to identify personal and work behaviors that are significantly associated with neck pain in fighter pilots. Methods: Eighty-two Royal Australian Air Force fighter pilots were surveyed about their flying experience, neck pain prevalence, and prevention. Multinomial logistic regressions were used to fit models between pilots' neck pain during and after flight and a range of personal and work characteristics. Results: In-flight neck pain was very weakly, yet positively associated with flight hours. Duration of postflight pain was positively associated with the weekly desktop work hours and the sum of preventative actions taken in flight. The duration pilots were considered temporarily medically unfit for flying was positively associated with pilots' age and their weekly desktop work hours. Discussion: The risk factors identified by the current study should guide neck pain prevention for fighter pilots. In particular, reducing desktop working hours as well as incorporating specific neck-strengthening exercises and in-flight bracing actions should be considered by agencies to help alleviating neck pain in their pilots.

INTRODUCTION

High-performance combat (i.e., “fighter”) pilots are critical in maintaining the integrity and safety of a nation's airspace. Fighter pilots perform many maneuvers, such as, rolls, turns, and climbs, while flying.¹ These maneuvers are fundamental for both defense and offense against enemy aircraft.² While executing these maneuvers, the aircraft and the fighter pilot's body are exposed to forces equivalent to up to eight times that of gravity (i.e., +8 Gz).² Fighter pilots also have a number of duties while on the ground, including mission planning, briefings and debriefings as well as preparing materials and other miscellaneous administration tasks.³

There are numerous reports of fighter pilots suffering from cervical spine injuries, with the most common being strains or stiffness of the neck muscles.^{2,4} In Australia and the United States, 85% of F/A 18 fighter pilots reported having experienced neck pain during their flying careers.^{1,5} Their neck injuries can be categorized into two main subgroups⁶: acute neck injuries, which occur during or shortly after flight, and chronic neck injuries, which develop over time. In addition to the obvious health consequences, neck injuries can interfere with pilots' flying performance, concentration levels, situational awareness, and potentially the safety of themselves and their squadron.

To limit pilot's risk of injury and the consequences of existing injury, they maybe deemed temporarily medically unfit for flying (TMUFF) if they report neck pain.⁷ In a recent survey, 34/82 Royal Australian Air Force (RAAF) pilots had

been classified TMUFF because of neck pain with the average length of time being less than a week.⁷ Given the importance of maintaining pilot numbers and performance for airspace capability, determining which factors are implicated in the pilot's neck pain can guide prevention and management strategies to limit TMUFF periods. Existing research suggests that flying hours, desktop work hours, and exercise are all implicated in neck pain (or injury).^{2,3,8} No studies have quantified the relationship between these factors and neck pain/TMUFF in fighter pilots. Therefore, the aim of this study was to identify significant associations between personal characteristics such as flight hours, behavior such as the amount of exercise and neck pain during and after flight. These associates were investigated for the duration of worst and average pain levels as well as the duration that fighter pilots were considered TMUFF. These associations can then be thought of as “predictors” or “risk factors” for neck pain in high-performance combat pilots.

METHODS

Participants

The aim and purpose of this study with a brief description of the methodology were explained to all aircrew. All information was treated with strictest Study-In-Confidence and was not used to initiate medical treatment or Medical Employment Classification Review proceedings.

Eligible aircrew were current permanent or reserve RAAF aircrew (pilot, navigator and flight test engineers) either presently or previously qualified on a high-performance airframe, including students presently undergoing a conversion course onto a high-performance aircraft. For the purpose of this study, they were grouped together as one cohort. Personnel from foreign military organizations were excluded from this study as long-term follow-up (as part of a larger RAAF study) was expected to be problematic. All procedures were

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approved by the Australian Defence Human Research Ethics Committee and the Deakin University Human Research Ethics Committee.

Survey Instrument

The survey comprised 18 questions and was divided into six sections. These six sections broadly surveyed personal details and flying experience (section one), helmets and night vision goggles/helmet-mounted display systems usage (section two), preventative activities while flying to minimize the risk of neck pain and injury (section three), neck strain, pain or injury sustained (section four), neck pain management (section five), and neck pain prevention while flying (section six). Only sections one, three, four, and six were used in the study. Section one of the survey queried general information of the participants including self-reported anthropometry, flying history in hours, and the type of aircraft in which this experience was gained. Section three of the survey assessed the number of preventative actions used by the participants to minimize neck pain and injury during and after flight (Table I). Section four queried the existence of flight-related neck pain, the severity of such pain on a visual analogue scale of 0 (no pain) to 10 (worst possible pain), and the duration of the pain experienced postflight. Both the levels of pain severity and duration were surveyed for the worst and average episodes of flight-related neck pain experienced by the participant. The length of time the participants were TMUFF was also measured in this section. Section six investigated the amount of times the participants performed aerobic, resistance, and neck-specific exercises as well as any other neck pain prevention strategies conducted.

Data Analyses

The data were separated into dependent and independent variables. The dependent variables measured were “number of neck pain episodes during flight,” “number of neck pain episodes after flight,” “duration of worst episode,” “duration of average episode,” and “longest duration of TMUFF.” The categories for each variable are summarized in Table II.

TABLE I. List of Preventative Actions

Number	Preventative Action
1	Preflight neck stretching
2	In-flight Gz warm-up
3	Set head position before application of Gz
4	Restrict movement under Gz, move only under low Gz
5	Move upper body as well as head/neck
6	Use shoulders to aid rotation of head
7	Keep head aligned with body under Gz
8	Brace head against aircraft canopy
9	Brace head against ejection seat head box
10	Move head/neck in only one plane under Gz
11	Minimize overall exposure to Gz
12	Postflight neck stretch

TABLE II. Dependent Variable Categories

Dependent Variable and Category	Category Number and Description
No. of Neck Pain Episodes During and After Flight	0, No Pain 1, 1–3 Episodes 2, 4–10 Episodes 3, >10 Episodes
Duration Worst and Average Pain	0, No Pain 1, <12 Hours 2, 12–24 Hours 3, 24–96 Hours 4, >96 Hours
Longest Continuous TMUFF	0, Never 1, <1 Week 2, 1–2 Weeks 3, 3–4 Weeks 4, >1 Month

TABLE III. Exercise Categories

Category Number	Description
0	Never
12	Once a Month
24 ^a	1–3 Times a Month
52	Once a Week
156 ^b	2–5 Times a Week
365	Once a Day

^aThe middle value of 2 was used (2×12 months = 24).

^bMiddle value of 3 was used (3×52 weeks = 156).

The independent variables included were flight hours, age and height, the amount of exercise, the amount of preventative actions, and the amount of desktop hours. Independent variables also included the frequency with which participants performed aerobic, anaerobic, and neck exercises in a calendar year, which were categorized into groups (Table III). The number of preventative actions used by the pilots reflected a sum of all the actions out of 12, taken from the survey. For example, a value of “7”; means that a respondent used 7 of the 12 available actions. For a full list of the preventative actions, please refer to Table I.

Statistics

Multinomial logistic regressions were used in the current study since each dependent variable was categorical and had more than 2 outcomes.⁹ Backward stepwise regressions were performed since the study was exploratory in nature and to limit the chances of a type II error.⁹ Parameter estimates were used to establish the relationship between the independent and dependent variables, whereas odds ratios quantified the likelihood that a one unit increase in the independent variable would significantly change the dependent variable (compared to baseline).⁹ Significance level for all analyses was set at $p < 0.05$, with all data analysis being conducted with Statistical Package for Social Sciences V.17.0 (IBM SPSS,

Champaign, Illinois). All descriptive data are expressed as means $\pm$ SDs unless otherwise stated.

RESULTS

Eighty-two male pilots (31 ± 7 years, 180.6 ± 6.5 cm, 81.1 ± 8.6 kg, $2,013 \pm 1,570$ flying hours) responded to the survey. This is a response rate of approximately 96%. Descriptive data from the survey regarding the frequency, duration, and management of neck pain in fighter pilots were presented in a previous article.⁷

Number of Neck Pain Episodes During Flight

The model significantly predicted the number of neck pain episodes during flight ($p = 0.005$). The model included flight hours ($p = 0.005$) and excluded desktop hours ($p = 0.5450$), height ($p = 0.323$), anaerobic exercise ($p = 0.759$), neck exercise between flights ($p = 0.307$), aerobic exercise ($p = 0.310$) frequencies, preventative actions ($p = 0.228$), and age ($p = 0.250$). The relationship between the number of flight hours and the likelihood of increasing the number of in-flight pain episodes from none to 1–3, 4–10, and >10 , respectively, is presented in Table IV. As shown, an increase of flight hours was associated with a significant increase in the likelihood of pilots experiencing 4–10 pain episodes and >10 pain episodes in flight (compared to no pain). The odds ratio for this relationship was 1.001, which indicates that for a 1-hour

increase in flight time, the odds of the pilots suffering >4 episodes in flight, compared to no pain, would increase by 0.001 ($p = 0.010$).

Number of Neck Pain Episodes After Flight

The model significantly predicted the number of neck pain after flight ($p = 0.003$). It included neck exercise between flights ($p = 0.041$) and excluded flight hours ($p = 0.084$) and preventative actions in flight ($p = 0.080$), anaerobic exercise ($p = 0.789$), aerobic exercise ($p = 0.669$) frequencies, height ($p = 0.435$), age ($p = 0.376$), and desktop hours ($p = 0.342$). The relationship between the number of neck pain episodes after flight and the likelihood of increasing the number of postflight neck pain episodes from none to 1–3, 4–10, >10 , respectively, is presented in Table IV. As shown, neck exercise training frequency could not predict categories of post-flight neck pain.

Duration of Worst Pain Episode

The model significantly predicted the duration of worst pain episode ($p < 0.001$). It included flight hours ($p = 0.001$) and desktop hours ($p = 0.011$) and excluded anaerobic exercise ($p = 0.857$), neck exercise between flights ($p = 0.492$), aerobic exercise ($p = 0.345$) frequencies, age ($p = 0.361$), height ($p = 0.243$) and preventative actions ($p = 0.203$). The relationship between the number of flight and desktop hours and the likelihood of increasing the duration of worst neck pain is presented in Table V. As shown, an increase in desktop hours was associated with a significant increase in the likelihood of the duration of worst pain episode lasting >12 hours. The odds ratios for the worst pain lasting <12 hours, 12 to 24 hours, 24 to 96 hours, and >96 hours are 251.3, 295.2, 331.7, and 335.4, respectively. These ratios indicate that for a 1-hour increase in desktop hours, the odds that the duration of worst pain will last at least <12 hours increases by approximately 250 times, with higher odds for pain lasting longer than 12 hours (Table V).

Duration of Average Pain Episode

The model significantly predicted the duration of average pain episode ($p = 0.001$). It included flight hours ($p = 0.006$) and preventative actions ($p = 0.039$) and excluded desktop hours ($p = 0.979$), height ($p = 0.605$), neck exercise between flights ($p = 0.692$), anaerobic exercise ($p = 0.510$), aerobic exercise ($p = 0.943$) frequencies, and age ($p = 0.231$). The relationships between the number of flight hours and the number of preventative actions used in flight and the likelihood of increasing the duration of average pain episode are presented in Table V. As shown, an increase in preventative actions was associated with a significant increase in the likelihood that average pain episode will last between 12 and 96 hours. The odds ratios for <12 hours, 12 to 24 hours, 24 to 96 hours, and >96 hours are 1.8, 2.0, 1.8, and 2.0, respectively. These ratios indicate that increasing the sum of preventative

TABLE IV. Odds Ratio Table for Number of Neck Pain Episodes During and After Flight

	<i>B</i> (SE)	Odds Ratio (95% CI)
Neck Pain During Flight		
1–3 Episodes		
Intercept	−0.16 (0.569)	
Flight Hours	0.001 (0.000)	1.001 (1.000–1.001)
4–10 Episodes		
Intercept	−1.055 (0.628)	
Flight Hours	0.001 (0.000)*	1.001 (1.000–1.002)
>10 Episodes		
Intercept	−0.911 (0.616)	
Flight Hours	0.001 (0.000)*	1.001 (1.000–1.002)
Neck Pain After Flight		
1–3 Episodes		
Intercept	−0.556 (0.960)	
Neck Exercise	−0.007 (0.004)	0.993 (0.985–1.002)
Flight Hours	0.000 (0.000)	1.000 (0.999–1.000)
Preventative Actions	0.406 (0.198)*	1.501 (1.019–2.211)
4–10 Episodes		
Intercept	−1.808 (1.148)	
Neck Exercise	−0.008 (0.005)	0.992 (0.983–1.002)
Flight Hours	0.000 (0.000)	1.000 (1.000–1.001)
Preventative Actions	0.374 (0.218)	1.454 (0.948–2.230)
>10 Episodes		
Intercept	−2.389 (1.132)	
Neck Exercise	0.000 (0.004)	1.000 (0.993–1.008)
Flight Hours	0.000 (0.000)	1.000 (1.000–1.001)
Preventative Actions	0.486 (0.207)*	1.626 (1.084–2.439)

B = Beta Coefficient, SE = Standard Error, CI = Confidence Interval. * $p < 0.05$.

TABLE V. Odds Ratio Table for Duration of Worst and Average Pain Episodes

	<i>B</i> (SE)	Odds Ratio (95% CI)
Duration Worst		
<12 Hours		
Intercept	-1.933 (1.173)	
Flight Hours	0.002 (0.002)	1.002 (0.999–1.005)
Desktop Hours	5.527 (0.173)*	251.324 (179.148–352.580)
12–24 Hours		
Intercept	-1.1573 (1.158)	
Flight Hours	0.002 (0.002)	1.002 (0.999–1.005)
Desktop Hours	5.688 (0.168)*	295.237 (212.237–410.040)
24–96 Hours		
Intercept	-2.542 (1.193)	
Flight Hours	0.003 (0.002)	1.003 (1.000–1.006)
Desktop Hours	5.804 (0.131)*	331.714 (256.568–428.870)
>96 Hours		
Intercept	-2.996 (1.193)	
Flight Hours	0.003 (0.002)*	1.003 (1.000–1.006)
Desktop Hours	5.815 (0.000)*	335.409 (335.409–335.409)
Duration Average		
<12 Hours		
Intercept	-1.217 (1.066)	
Flight Hours	0.000 (0.000)	1.000 (0.999–1.000)
Preventative Actions	0.565 (0.231)*	1.759 (1.118–2.766)
12–24 Hours		
Intercept	-2.124 (1.248)	
Flight Hours	0.000 (0.000)	1.000 (0.999–1.000)
Preventative Actions	0.681 (255)*	1.976 (1.198–3.260)
24–96 Hours		
Intercept	-2.080 (1.134)	
Flight Hours	0.000 (0.000)	1.000 (1.000–1.001)
Preventative Actions	0.569 (0.232)*	1.766 (1.121–2.782)
>96 Hours		
Intercept	-5.124 (1.797)	
Flight Hours	0.001 (0.000)	1.001 (1.000–1.001)
Preventative Actions	0.698 (0.287)*	2.010 (1.145–3.528)

* $p < 0.05$.

actions in flight, from 7 to 8 for example, doubles the odds that the average pain episodes will last from 12 to 24 hours or >96 hours, compared to no pain. The amount of flight hours flown by the pilots was unable to predict the pain duration categories (Table V).

Duration of Longest Continuous TMUFF

The model significantly predicted the duration of longest continuous TMUFF ($p = 0.001$). It included age ($p = 0.001$), height ($p < 0.001$), neck exercise between flights ($p < 0.001$), anaerobic exercise ($p = 0.004$) frequencies, preventative actions ($p = 0.013$), and desktop hours ($p = 0.001$). It excluded flight hours ($p = 0.584$) and aerobic exercise frequency ($p = 0.229$). The relationships between age, height, neck exercise between flights, anaerobic exercise, preventative actions, and desktop hours and the likelihood of increas-

TABLE VI. Odds Ratio Table for Duration Longest Continuous TMUFF

	<i>B</i> (SE)	Odds Ratio (95% CI)
Duration TMUFF		
<1 Week		
Intercept	4.035 (9.621)	
Age	0.138 (0.048)*	1.148 (1.05–1.26)
Height	-0.055 (0.053)	0.946 (0.85–1.05)
Neck Exercise	0.001 (0.003)	1.001 (1.00–1.001)
Anaerobic Exercise	-0.007 (0.005)	0.993 (0.98–1.00)
Preventative Actions	-0.058 (0.150)	0.944 (0.70–1.27)
Desktop Hours	0.471 (176)*	1.602 (1.14–2.26)
1–2 Weeks		
Intercept	-3.898 (19.261)	
Age	0.172 (0.086)	1.187 (1.19–1.41)
Height	-0.053 (0.103)	0.948 (0.95–1.16)
Neck Exercise	0.008 (0.006)	1.008 (1.01–1.02)
Anaerobic Exercise	0.013 (0.009)	1.013 (1.01–1.03)
Preventative Actions	0.457 (0.285)	1.58 (1.58–2.76)
Desktop Hours	0.116 (0.281)	1.123 (1.12–1.95)

* $p < 0.05$

ing the duration of longest continuous TMUFF are presented in Table VI. As shown, an increase in age and desktop hours was associated with a significant increase in the likelihood that the pilots were TMUFF for <1 week. The odds ratios of 1.15 for age indicates that for every 1 year added to the age of the pilots, the odds of the pilots being declared TMUFF for <1 week increased by 1.15. The odds ratio of 1.6 for desktop hours indicates that the pilots being declared TMUFF <1 week increased by 1.6 for every 1-hour increase in their desktop hours. Finally, the height of the pilots, the frequency of neck and anaerobic exercises, and preventative actions were unable to predict categories of TMUFF duration.

DISCUSSION

The purpose of this study was to identify significant predictors of neck pain in RAAF fighter pilots. Participant's flight hours predicted their number of neck pain episodes during flight, whereas their flight hours, the frequency with which they performed neck exercise between flights, and the sum of preventative actions they performed in flight predicted neck pain after flight. The duration of participant's worst pain episode was predicted by their flight hours and their weekly desktop work hours, whereas the duration of their average pain episode was predicted by their flight hours and their use of preventative actions in flight. Further, the duration of participant's longest continuous TMUFF was predicted by participant's age, height, the frequency with which they performed neck and resistance exercises, the sum of the preventative actions they performed in flight, and the amount of desktop hours they worked in a week.

An increase in the number of flight hours that the participants accrued was significantly associated with an increase of neck pain during flight and the duration of the worst pain episode postflight. However, in both cases, these were very

weak associations. This is contrary to De Loose et al³ who reported that the quantity of F-16 flight hours had no influence on the occurrence of neck pain. The current study measured flight hours in terms of total flying hours not just those performed in a specific aircraft, as specified by De Loose et al.³ It is possible that if De Loose et al³ included all their pilots' flying hours, their results may have been different. The findings of the current study, however, concur with the observations of Albano and Stanford² who found that flight hours, although not statistically significant, had a weak relationship with neck pain. The likely mechanism behind the relationship between flight hours and neck pain may be the repeated exposure to high gravitational forces in flight.¹⁰ These forces can alter the head-neck segment biomechanics and may explain, at least in part, the neck pain (and possible injury) in fighter pilots.¹¹ The significant relationship identified in the current study, though very weak could inform future investigations into the relationships between exposure to specific Gz forces in flight and neck pain.

The current study found that an increase in neck pain after flight was significantly associated with a decreased frequency of performing neck exercise between flights. This result infers that a decrease in neck exercise training during the week may lead to increased pain after flight. This finding supports the premise of the utility of neck-specific conditioning exercises in this occupational group. Ang et al¹² reported that a significant decrease in the prevalence of neck pain in 68 Swedish helicopter pilots, following a neck exercise intervention.⁴ As the current study used a retrospective design, it cannot be ruled out that those fighter pilots with existing neck pain postflight participate in less neck exercise to not exacerbate the pain in later flights. Interestingly, a very weak, yet significantly positive relationship was identified between the duration of TMUFF and the frequency of neck-strengthening exercises performed between flights (Table VI). Though this result could infer that more neck-specific training increases the duration of TMUFF, it is equally plausible that pilots on TMUFF perform more neck strengthening during this period in an effort to rehabilitate. Again, the retrospective study design limits the identification of causal relationships. A randomized control trial investigating the effect of neck-specific training in the reduction of neck pain in this occupational cohort should be trialed to identify the value (or not) of neck exercise training and neck pain in fighter pilots.

Postflight neck pain was significantly associated with the frequency of neck-specific training and flight hours, yet neither variable could distinguish between the levels of pain postflight (compared to no pain) or TMUFF. One suggestion for this result could be due to the influence of large between-participant variation. Regression and correlation analyses seek to identify linear relationships between 2 (or more) variables. The likelihood of identifying linear relationships improved when examining data sets with large between-participant variation.¹³ In contrast, more homogenous data, with smaller between-participant variation, such as parameter

estimates comparing each outcome category to baseline, are more difficult to identify linear relationships.¹³

The duration of pilot's average pain was positively associated with the number of preventative actions they performed during flight. On first inspection, it is surprising that an increase in the number of preventative actions would be significantly associated with an increase in the length of average postflight pain. These actions include restricting movement under Gz, moving only under low Gz, bracing the head against aircraft canopy, and bracing the head against the ejection seat head box.⁷ It is possible that since these movements involve substantial activation of the neck musculature, they put further stress on these muscles, causing them to become even more fatigued.⁴ Muscle fatigue has been suggested as a risk factor for neck injuries as it interferes with muscle coordination,⁴ which could in turn, increase the risk of neck pain. An alternatively explanation for this finding may be that pilots who already experience neck pain, make more use of these techniques in the hope of protecting their already vulnerable neck. Because of the design of the current study, however, cause and effect cannot be resolved so it is unclear whether preventative actions cause or exacerbate existing pain or are merely associated with longer postflight pain through another yet to be identified mechanism. To find the answer to this question, a randomized control trial comparing pain levels for one group performing preventative actions in flight and the other not performing preventative actions in flight could be undertaken. The practicalities of such a trial for both experimental and control group members would, however, need careful consideration.

The current study found that the amount of desktop hours per week performed by the pilots was positively and significantly associated with an increase in the duration of their worst neck pain episodes postflight. This finding supports existing research showing work-related neck disorders are common in office workers, particularly those who have high computer usage time.¹⁴ De Loose et al¹⁵ studied military office workers and showed that sufferers of neck pain within this population conducted significantly more computer working time.¹⁵ Although desktop activities and neck pain are a common association, the specific origin of neck pain, be it posture, stress levels, or physical health,¹⁶ is not known, making targeted interventions difficult. However, a direct consequence from the result of the current study may be to decrease pilots' weekly desktop hours. This may be beneficial (irrespective of the mechanism) in alleviating neck pain.

The current study found that the pilot's length of continuous TMUFF status was positively associated with their age. The positive relationship between age and length of TMUFF (self or Aviation Medical Officer imposed) is likely to be mediated by pain or injury.⁷ From a review of the neck pain literature, McLean et al¹⁷ showed that there is strong evidence to suggest that in the general population, people in the age range of 45 to 55 years were twice as likely to develop neck pain compared to their younger counterparts.¹⁷ There

are a number of different mechanisms that could account for the increase in pain with increasing age, with some authors suggesting that the increase in pain with age may be due to the increasing degeneration of the cervical spine with age.¹⁸ The decrease in mobility and strength of the spine, and the degeneration of the facet joints,¹⁹ could also cause the increase in pain and injury in older fighter pilots. Also, longer periods of TMUFF for older pilots could reflect their decreased ability to recover from the injury compared to their younger counterparts.¹⁹ The combination of increased vulnerability to injury and slower healing may contribute to the increased weakness and fatigability of neck muscles in older fighter pilots,¹⁹ which would prolong TMUFF.

The results of the current study show that both aerobic and resistance training frequency were not significantly associated with predicting neck pain or TMUFF time in fighter pilots. This is contrary to previous literature, which suggests whole-body strength training as a possible preventative mechanism for mechanical neck disorders.^{2,20,22} Similarly, Oldervoll, et al²³ showed that aerobic training sessions significantly reduced neck muscle pain in hospital staff after 8 weeks of training.²³ It is possible that fighter pilots, by virtue of their high risk for neck pain, require more specific conditioning than other populations, as suggested by the negative relationship between neck pain and neck strength training frequency (Table IV). Alternatively, the current findings could reflect limitations in the study design as the training used by pilots in the current study were self reported and not measured; only the frequency of exercise was surveyed. The survey instrument used did not ask the pilots to record the intensity of the training sessions. Without capturing a range of pertinent training variables (frequency, intensity, time, and type), it is difficult to assess training effectiveness and whether such training is related to neck pain. Future studies should try and capture intensity of training by incorporating rating of perceived exertion and training time into their survey tools.

Neck-specific conditioning interventions should be trialed by these agencies as this type of conditioning has been found to be effective in decreasing injury and pain in fighter pilots.² An increase in the rest periods or an alternate flying schedule for older pilots or those with increased exposure to flight and Gz, such as those with higher flight hours (>3,000), while operationally impractical could also be trialed. Given that desktop hours is a significant factor for neck pain and TMUFF in fighter pilots, a reduction in this type of work would be very beneficial to fighter pilots around the world. A possible method for reducing these hours is to engage administrative assistants to assist pilots with completing their designated paper work, wherever possible. Although hiring new staff may be costly, the authors believe these costs are insignificant compared to the cost associated with TMUFF fighter pilots and the rehabilitation costs once these injuries have been sustained.

The current survey was conducted at a single time point, making cause and effect difficult to infer as the nominated

dependent and independent variables in this study may have been interacting in the opposite directions. For example, existing neck pain may have caused pilots to increase their frequency of bracing to limit further damage. The current study also overfitted the regression model with more independent variables than commonly suggested for a sample size of 82 respondents.⁹ The authors feel, however, that with such a valuable and specialized cohort, violations of the ratio of respondents to independent variables should not undervalue the results of the current study. Future studies should be directed at investigating discrete time points in fighter pilot work, for example, analyses of the effect of preceding desktop work or exercise to flying should be performed.

Fighter pilots are vital to the safety and security of their nation; however, as an occupational group, they are highly susceptible to neck pain and injury. The results of this study indicate that neck pain in fighter pilots can be predicted, at least in part, by regression models using self-reported pain data and lifestyle factors. Risk factors such as the number of flight hours, the age of the pilot, the amount of desktop hours they work, and the frequency with which they exercise their neck all have significant association with neck pain in fighter pilots. These results can be used to guide prevention strategies for airforces to consider as they move to limit the amount of injuries their pilots suffer, which in turn optimizes the effectiveness of their workforce and increases the safety of their country.

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REFERENCES

1. Newmann D: +Gz-induced neck injuries in Royal Australian Air Force fighter pilots. *Aviat Space Environ Med* 1997; 68: 520–4.
2. Albano J, Stanford J: Prevention of minor neck injuries in F-16 pilots. *Aviat Space Environ Med* 1998; 69: 119–39.
3. De Loose V, et al: Individual, work-, and flight-related issues in F-16 pilots reporting neck pain. *Aviat Space Environ Med* 2008; 79(8): 779–83.
4. Ang B, Linder J, Harms-Ringdahl K: Neck strength and myoelectric fatigue in fighter and helicopter pilots with a history of neck pain. *Aviat Space Environ Med* 2005; 76(4): 375–80.
5. Burnett A, Naumann F, Burton E: Flight training effect on the cervical muscle isometric strength of trainee pilots. *Aviat Space Environ Med* 2004; 75(7): 611–5.
6. Green ND, Brown L: Head positioning and neck muscle activation during air combat. *Aviat Space Environ Med* 2001; 75(8): 676–80.
7. Netto K, et al: Management of neck injury in Royal Australian Airforce fast jet aircrew. *Mil Med* 2011; 176(1): 106–9.
8. Ariens G, et al: Are neck flexion, neck rotation and sitting at work risk factors for neck pain: results of a prospective cohort study. *Occup Environ Med* 2001; 58: 200–7.
9. Field A (editor): *Discovering Statistics Using SPSS*, Ed 3. London, Sage, 2009.
10. Green ND: Acute soft tissue neck injury from unexpected acceleration. *Aviat Space Environ Med* 2003; 74(10): 1085–90.

11. Lecompte J, et al: Neck strength and EMG activity in fighter pilots with episodic neck pain. *Aviat Space Environ Med* 2008; 79(10): 947–51.
 12. Ang BO, Monnier A, Harms-Ringdahl K: Neck/shoulder exercise for neck pain in Air Force helicopter pilots. *Spine* 2009; 34(16): 544–51.
 13. Atkinson G, Nevill AM: Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med* 1998; 26(4): 217–38.
 14. Cagnie B, et al: Individual and work related risk factors for neck pain among office workers: a cross sectional study. *Eur Spine J* 2007; 16: 679–86.
 15. De Loose V, et al: Prevalence and risk factors of neck pain in military office workers. *Mil Med* 2008; 173(5): 474–8.
 16. Green B: A literature review of neck pain associated with computer use: public health implications. *J Can Chiropr Assoc* 2008; 52(3): 161–8.
 17. McLean S, et al: Risk factors for the onset of non-specific neck pain: a systematic review. *J Epidemiol Community Health* 2010; 64: 565–72.
 18. Viikari-Juntura E, et al: Longitudinal study on work related and individual risk factors affecting radiating neck pain. *Occup Environ Med* 2001; 58: 345–52.
 19. Buckwalter J, et al: Soft tissue aging and musculoskeletal function. *J Bone Joint Surg [Am]* 1993; 75: 1533–48.
 20. Sarig-Bahat H: Evidence for exercise therapy in mechanical neck disorders. *Man Ther* 2003; 8(1): 10–20.
 21. Burton R, et al: Cervical spinal injury from repeated exposures to sustained acceleration. RTO TR4. Cadex, France, NATO Research and Technology Organization, 1999.
 22. Linton SJ, van Tulder MW: Preventive interventions for back and neck pain problems. what is the evidence? *Spine* 2001; 26(7): 778–87.
 23. Oldervoll L, et al: Comparison of two physical exercise programs for the early intervention of pain in the neck, shoulder and lower back in female hospital staff. *J Rehabil Med* 2001; 33: 156–61.
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Neck pain among fighter pilots after the introduction of the JHMCS helmet and NVG in their environment.

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Abstract

INTRODUCTION: Neck pain is a common complaint among fighter pilots. With implementation of the joint helmet mounted cuing system (JHMCS), the strain on the pilot's neck has increased.

METHODS: We surveyed 58 F-16 pilots from the Royal Danish Air Force by anonymous questionnaires. More than half of these pilots used JHMCS regularly.

RESULTS: The response rate was 100%. Of the pilots, 97% experienced neck pain in flight or shortly after flying, 83% within the last year. Right side neck pain was significantly more frequent than left side, odds ratio 3.25. There was a strong tendency toward predominant right-sided shoulder pain. The pilots reported that combined rotation and extension movements were especially hazardous. Only 1 in 10 pilots moved his head independent of G-load. Neck pain influenced operational flying, especially the ability to perform a "check six" movement sufficiently, and affected flying with high G loads as occurs in basic fighter maneuvers and air combat maneuvering.

DISCUSSION: To avoid neck problems the majority of pilots aim to avoid certain head movements and to fix their neck before exposing themselves to high +Gz loads. With the implementation of JHMCS, two conflicting goals are evident and working at cross-purposes. A pilot's head should remain stationary while exposed to high +Gz loads. However, maximizing the advantages of JHMCS

encourages the pilot to move his head sharply while exposed to high +Gz loads. Training programs to help the pilots cope with these challenges are warranted.

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