Kenneth L. Cameron
Brett D. Owens *Editors*

Musculoskeletal Injuries in the Military

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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.

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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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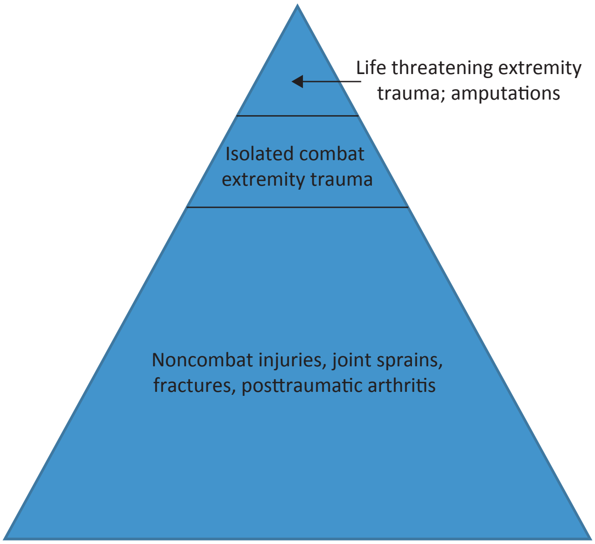

Fig. 1.1 The musculoskeletal injury "iceberg." The "tip" comprises severe injuries and amputations that have received the most attention to date by the press, researchers, and funding sources. The "base" of the iceberg may be less severe and less visible but represents a larger burden of injury and disease

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 × 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.

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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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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].

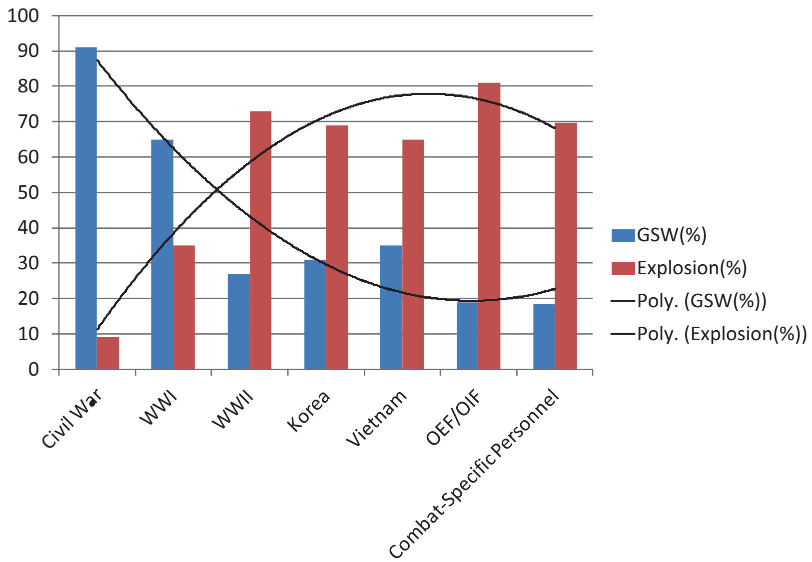

Fig. 2.1 Historical comparison of wounding patterns by conflict for major military engagements of the USA from the Civil War (1861–1865) to the present. Data for combat-specific personnel are derived from the Iraq and Afghanistan conflicts as reported by Schoenfeld et al. [19]. *WWI* World War I, *WWII*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

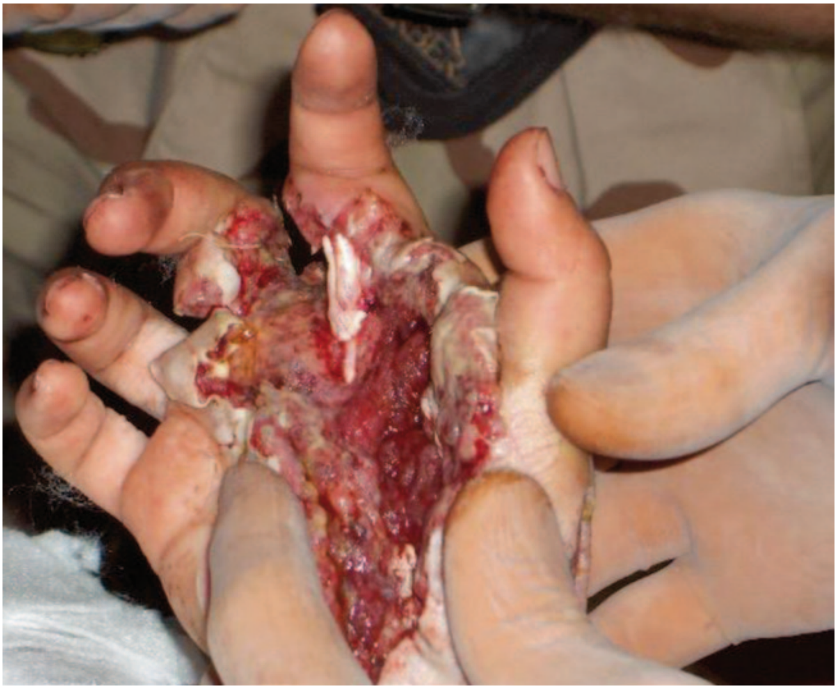

Fig. 2.5 High-velocity gunshot wound to the hand sustained by a soldier in Iraq

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 × 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.

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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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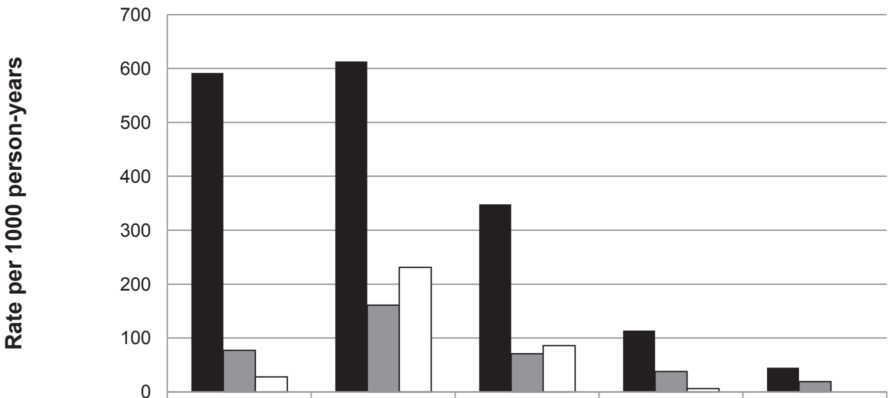
over the last century [3, 6, 10]. Understanding the factors associated with the distribution and impact of DNBIs is critical information for effective logistical planning and providing adequate medical support during combat operations [7]. Understanding the burden of DNBIs is also important in planning 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



	WWII	Korea	Vietnam	Desert Shield/Storm	Bosnia
■ Disease	592	613	348	114	45
■ Non-Battle Injury	77	161	71	38	19
□ Battle Injury	28	231	86	6	0

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 (TRAC^{2}ES), which is used for tracking aeromedical evacuations from theater [17]. The TRAC^{2}ES 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 TRAC^{2}ES 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 TRAC^{2}ES 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 TRAC^{2}ES 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 TRAC^{2}ES 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 TRAC^{2}ES 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 TRAC^{2}ES 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 TRAC^{2}ES 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, DNBIs 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 DNBIs reported, injury and musculoskeletal 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

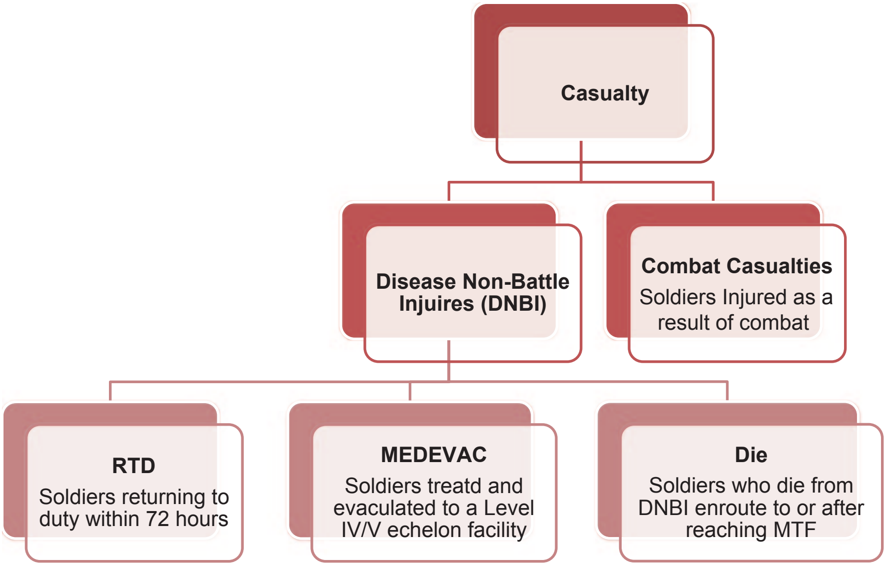


Fig. 3.2 Definitions and classification scheme of military casualties. *MTF* military treatment facility, *RTD* return to duty, *MEDEVAC* medical evacuation. (Adapted from Waterman et al. [8])

(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 DNBIs 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 injures 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 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 DNBIs 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 DNBIs 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 DNBIs 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 DNBIs and NBIs during deployments, and these data are being utilized to estimate medical resource needs with increasing accuracy. However, as noted by Wojick 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.

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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 softball. 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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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 "recycled" 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

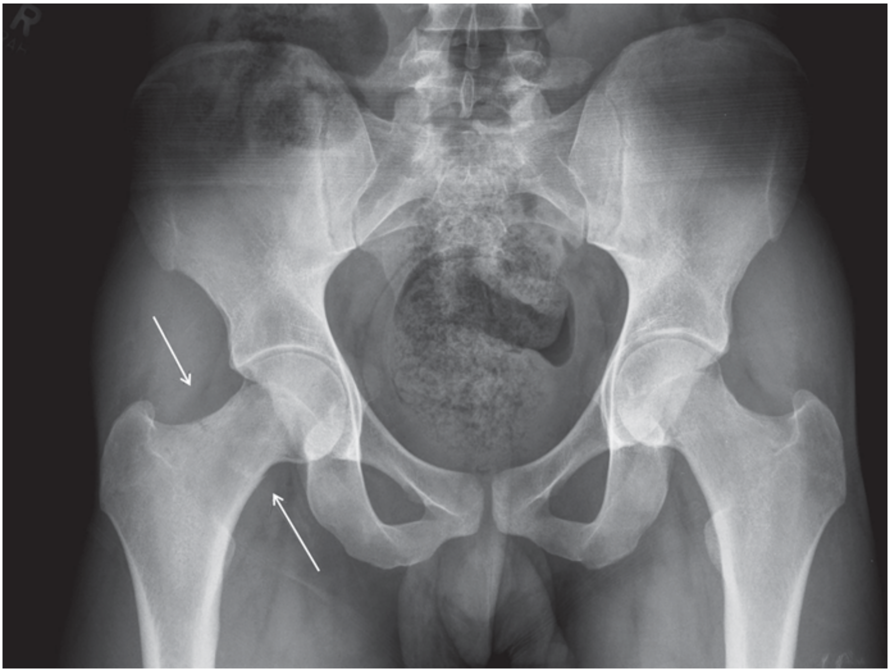

Fig. 5.1 Grade 4 stress fracture of the femoral neck

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

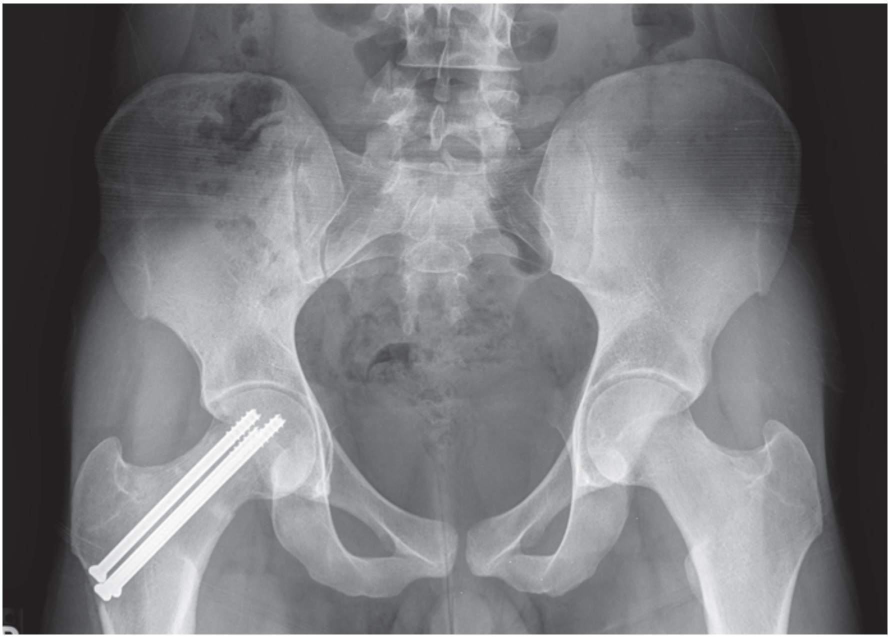

Fig. 5.2 Open reduction and internal fixation of femoral neck stress fracture

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 dependending 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

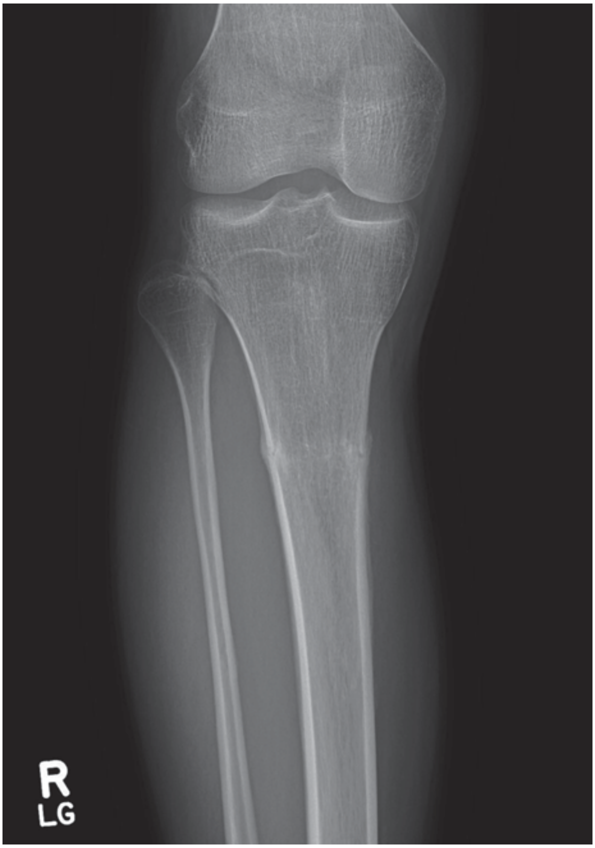

Fig. 5.3 Tibial shaft stress fracture

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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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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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 Laterjet 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 Laterjet 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 faired 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.

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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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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].

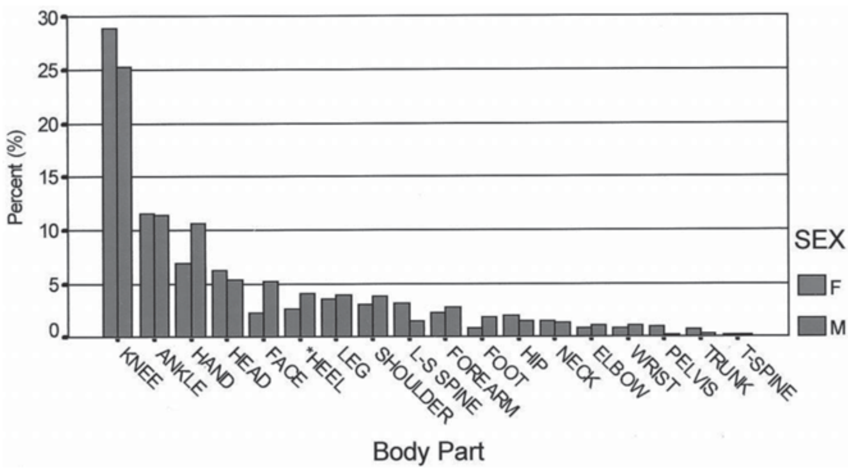

Fig. 7.1 Percent distribution of body areas injured in sports by gender [5]

Shoulder problems are common among US military service members and shoulder pain is a frequent complaint among service members who present to healthcare 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

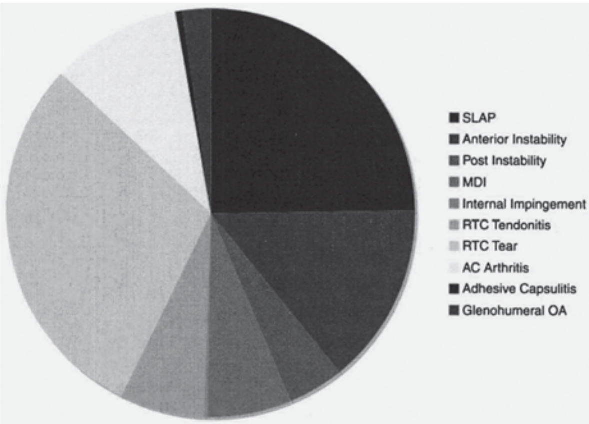

Fig. 7.2 Distribution of conditions in military patients presenting to orthopedic surgeons for shoulder pain [9]. *SLAP* superior labrum anterior posterior, *MDI* multidirectional instability, *RTC* rotator cuff, *AC* acromioclavicular, *OA* osteoarthritis

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].

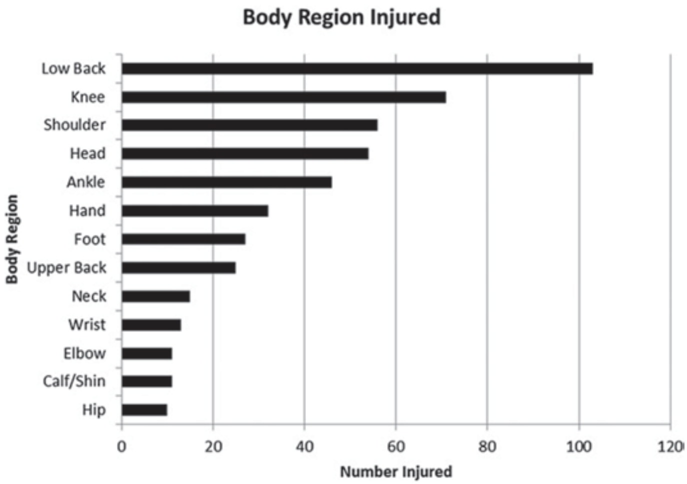

Fig. 7.3 Anatomical body regions injured most frequently during a 12-month deployment to Afghanistan [15]

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 DNBIs [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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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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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

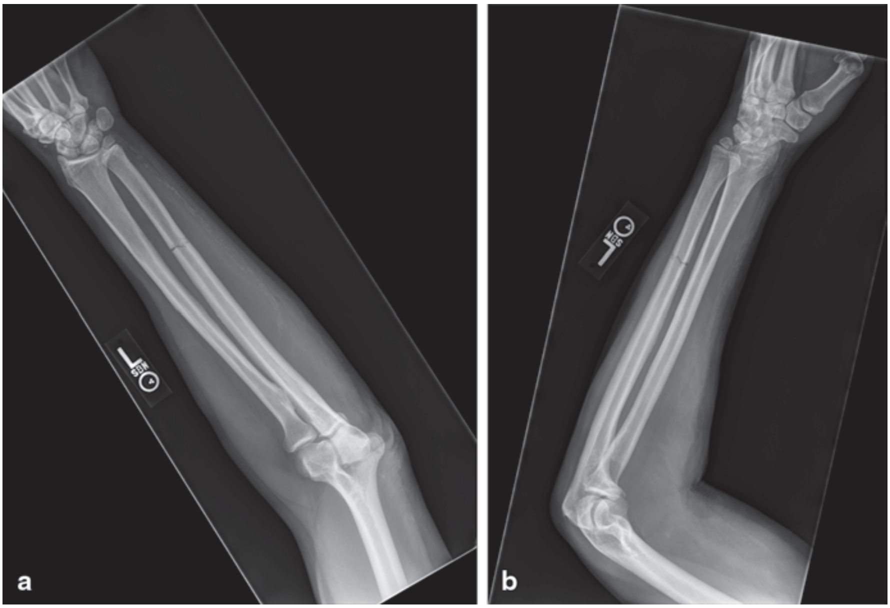

Fig. 8.1 **a** Posteroanterior and **b** lateral radiographs of the forearm with ulnar stress fracture

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 °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 Stannard 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

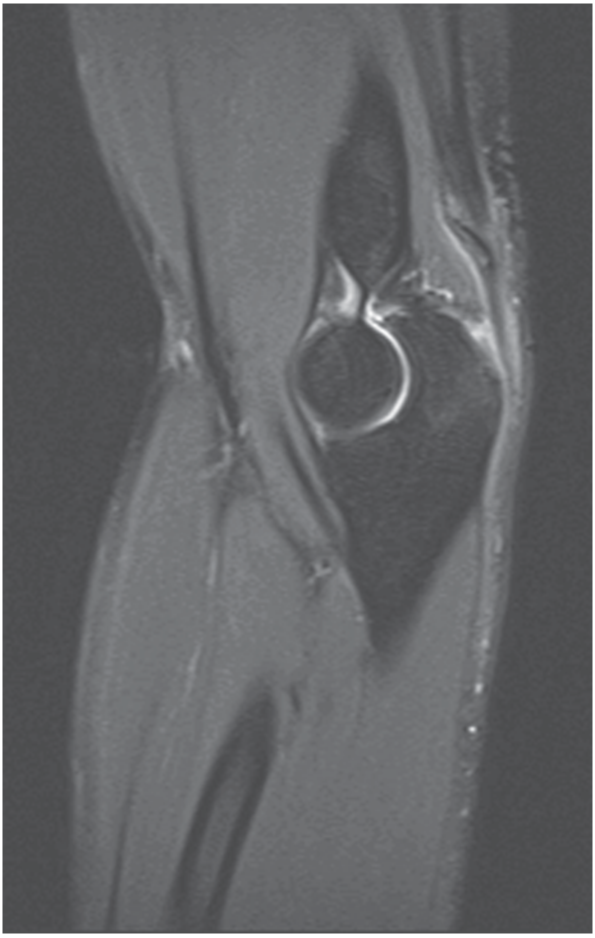

Fig. 8.2 MRI image of low-energy triceps rupture

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 noncombat 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 insuffiency 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 immunoglobin 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].

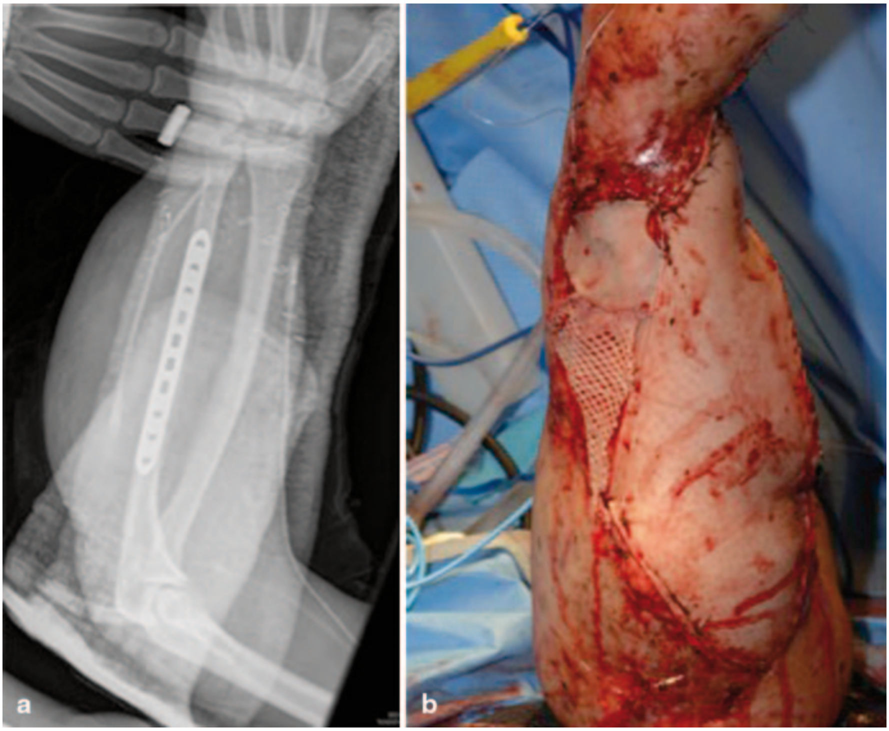

Fig. 8.4 After initial injury and battlefield tourniquet placement to his right upper and bilateral lower extremities, the patient was medically evacuated to the Role 3 medical facilities in Kandahar, Afghanistan, where an initial irrigation and debridement was performed on his right upper extremity. 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.

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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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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.

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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 DNBIs [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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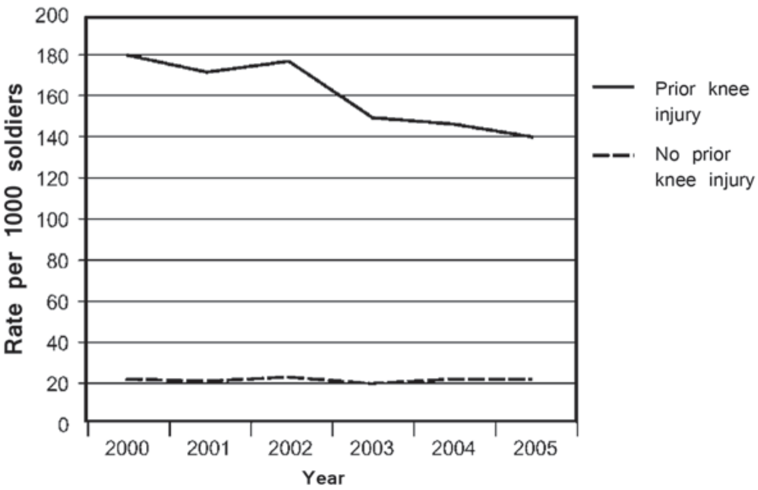

Fig. 10.1 Rates of knee injury in active duty Army, 2000–2005: stratified by prior knee injury status (Rate per 1000 soldiers may fall in more than one category per year) [6]

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 %. Menisectomy 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 meniscocapuslar 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]

	Traumatic amputees		General population[a]	
OA type	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 injures 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]

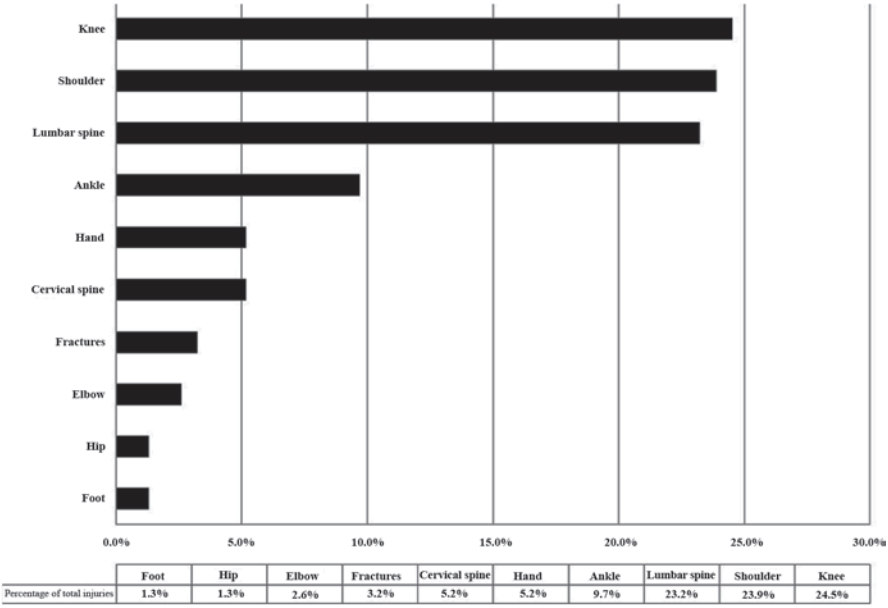

Fig. 10.2 Frequency of injury per body part in combatives [78]

Table 10.3 Regional distribution of lower extremity injuries reported in military personnel [33]

				Site (% of injuries)				
Study	Year	Population	Observation 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 infantery, $N = 303$; 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.

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Chapter 11
Lower Leg, Ankle, and Foot Injuries

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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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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, patients 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 investigated 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 cm^2 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.

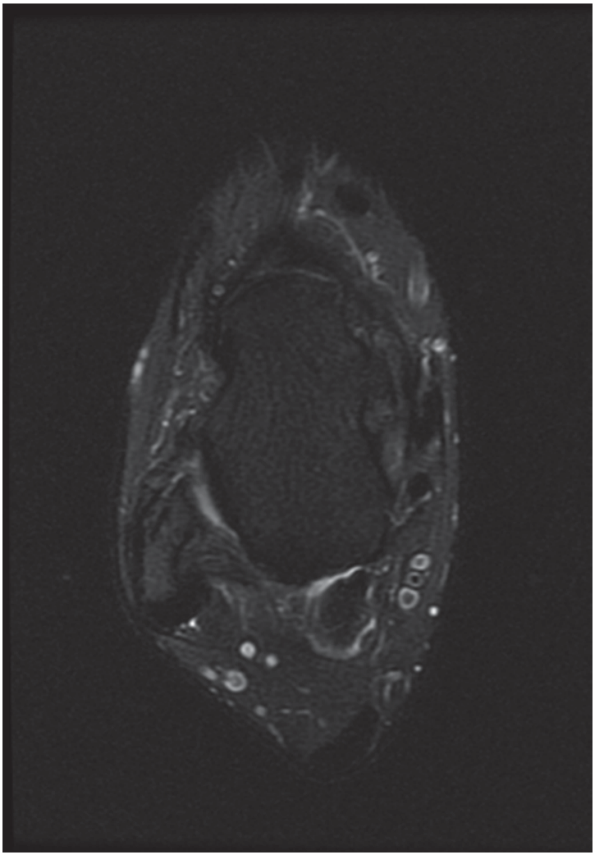

Fig. 11.4 Axial T2 MRI—anterior talofibular ligament (ATFL) disruption

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 stabilometry 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 networks 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 diminished 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), followed 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 competition has been synonymously used to describe both intensity of competition (i.e., practice vs. game) and level of skill (e.g., recreational, intercollegiate, and professional). 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 report 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

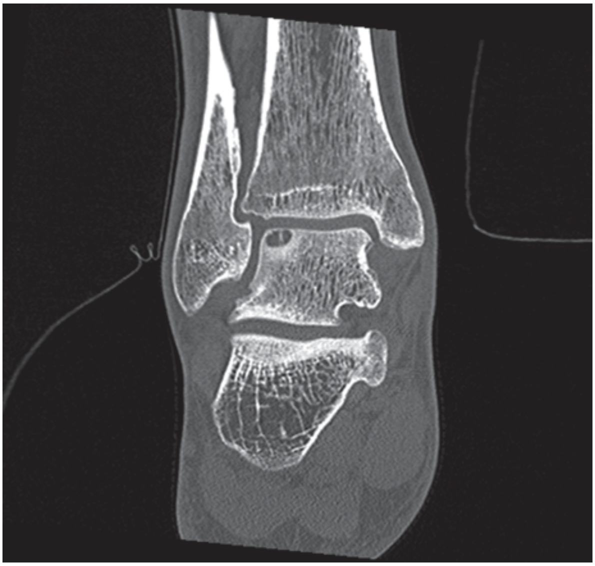

Fig. 11.6 Coronal CT—osteochondral lesion of the talus

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-

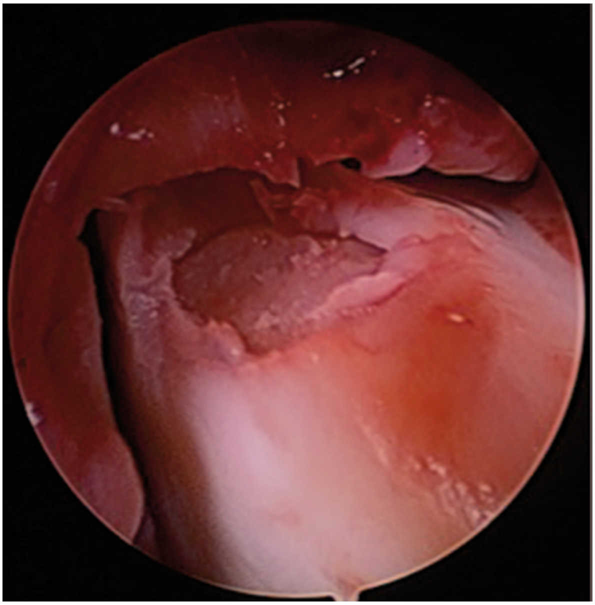

Fig. 11.9 Intraoperative arthroscopic image of lateral osteochondral lesion of the talus

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

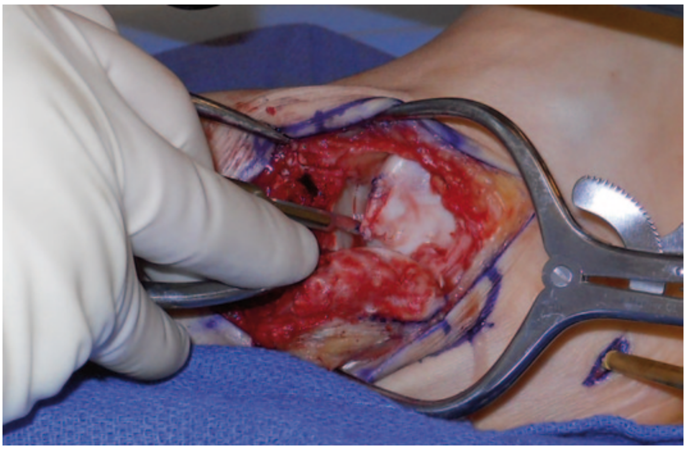

Fig. 11.10 Intraoperative open image of lateral osteochondral lesion of talus

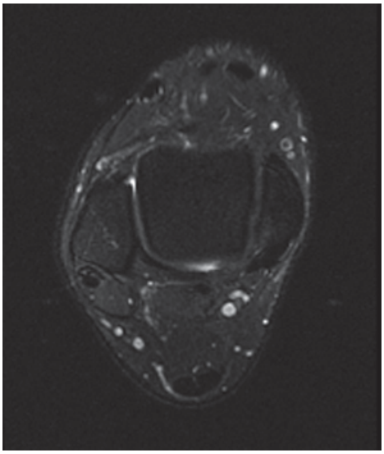

Fig. 11.11 Axial T2 MRI—peroneus brevis tear

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-

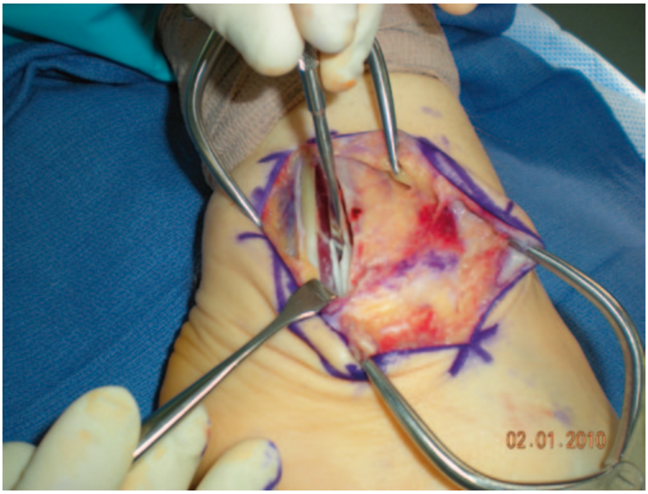

Fig. 11.12 Lateral ankle intraoperative image—longitudinal peroneus brevis tear

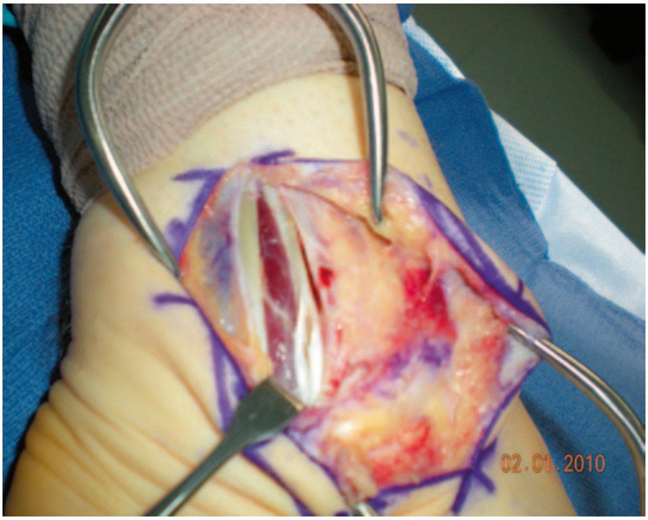

Fig. 11.13 Lateral ankle intraoperative image—longitudinal peroneus brevis tear

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 metatatarsal 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.

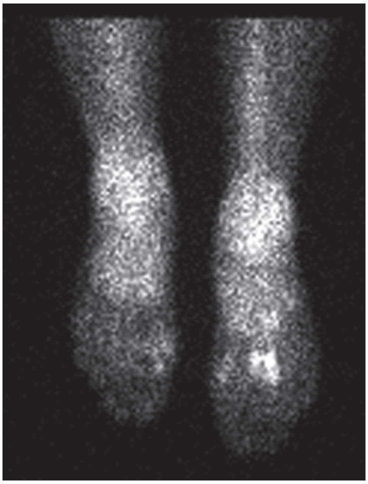

Fig. 11.22 Bone scan showing uptake at third metatarsal

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.

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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, cervicalgia, 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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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].

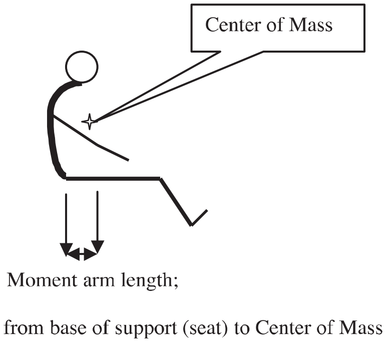
c. Aviators

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 20[6]. 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 win 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 unprotecte (Fig. 12.2).

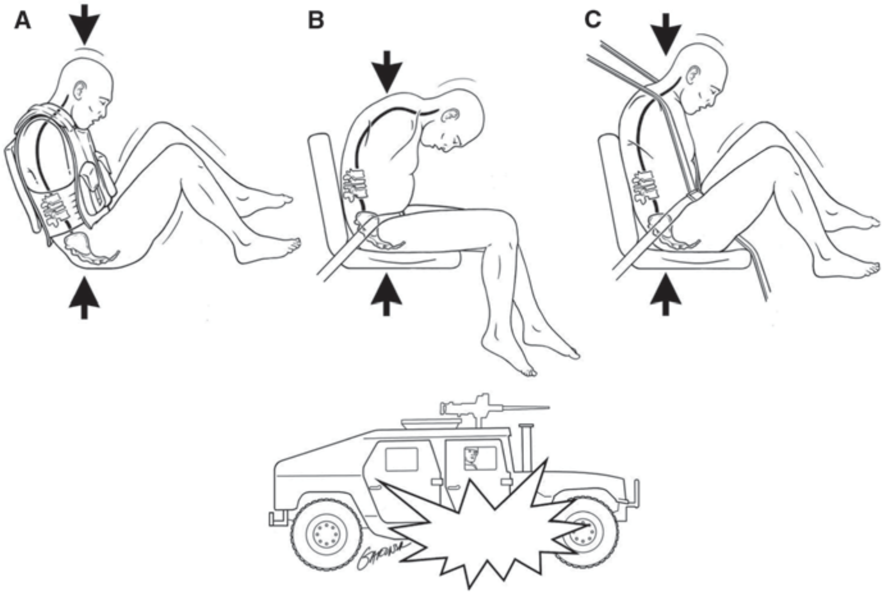


Fig. 12.2 Rigid body armor and vehicular restraints provide relative stability to the thoracic and upper lumbar spine but leaves the lumbosacral junction relatively unprotected

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].

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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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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*

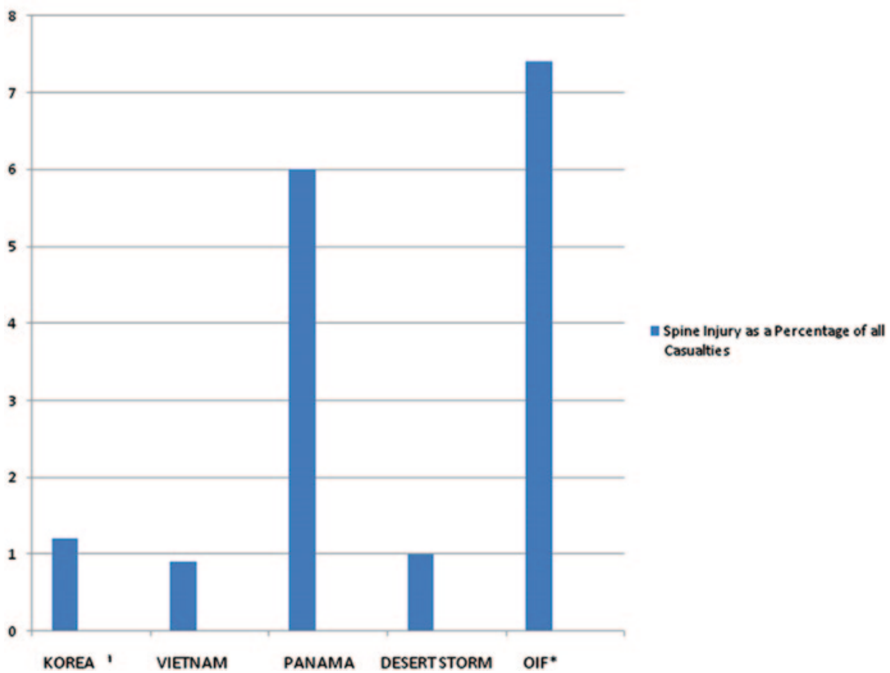

Fig. 13.1 Bar graph comparing the incidence of all spine injuries as percentage of total combat-related injuries between the Korean War and Operation Iraqi Freedom. (Reproduced from Schoenfeld [6]; with permission from Springer)

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)	p 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

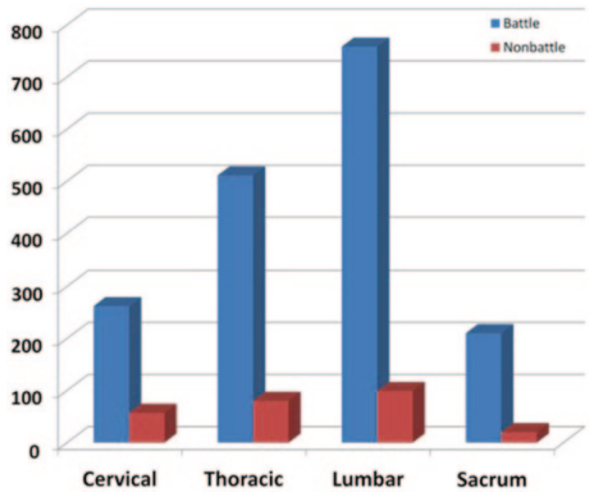

Fig. 13.2 Bar graph depicting the anatomic distribution of spine injuries sustained during Operation Iraqi Freedom and Operation Enduring Freedom between 2001 and 2009. Cervical trauma accounts for 14% of all combat-related injuries and 21% of all noncombat injuries. (Taken from Blair et al. [25]; with 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*

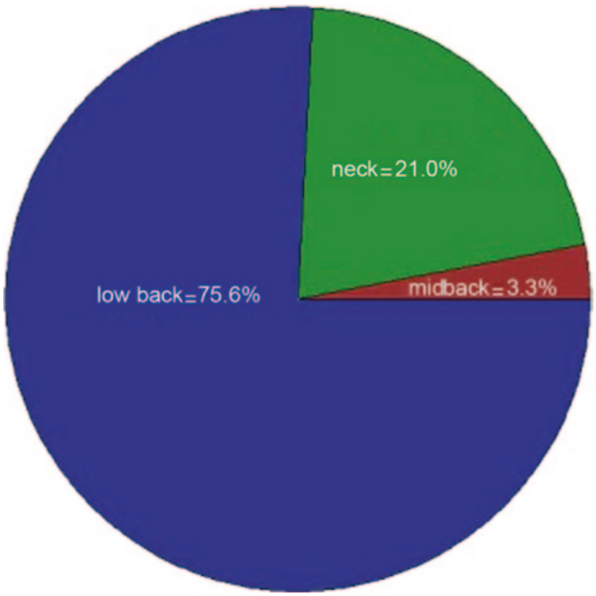

Fig. 13.3 Pie chart showing the breakdown of spinal pain by region, with neck and cervical pain representing 21 % of all spinal complaints. (Taken from Cohen et al. [30]; with permission from Springer)

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 guerilla 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	*Implosion injuries* 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) *Spalling injuries* 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].

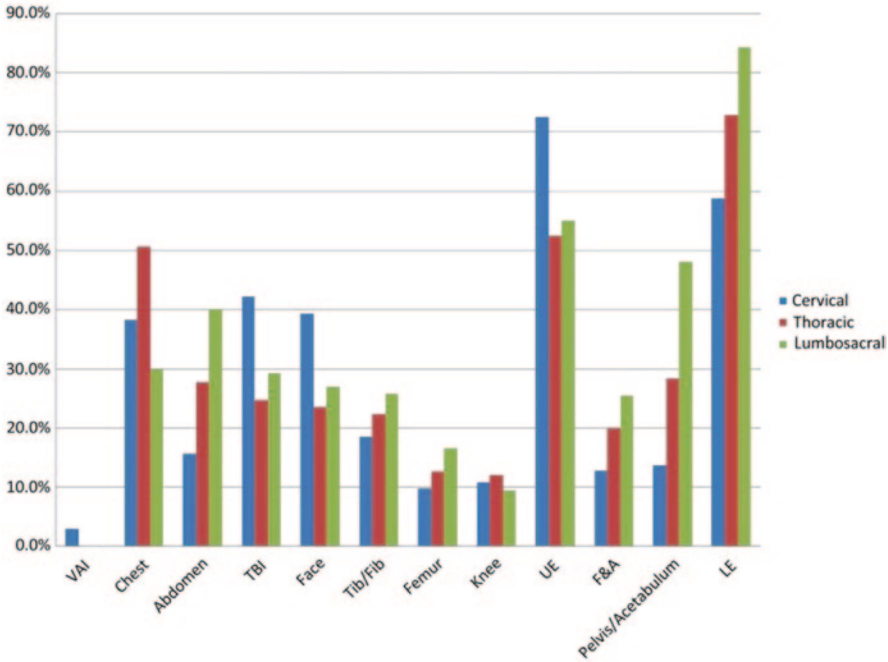

Fig. 13.4 Graphical representation of the percentage and distribution of patients sustaining associated injuries by spine region. *VAI* vertebral artery injury, *TBI* traumatic brain injury, *Tib/Fib* tibia/fibula, *UE* upper extremity, *F&A* foot and ankle, *LE* lower extremity. (Reproduced from Patzkowski 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 tomogrpahy 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].

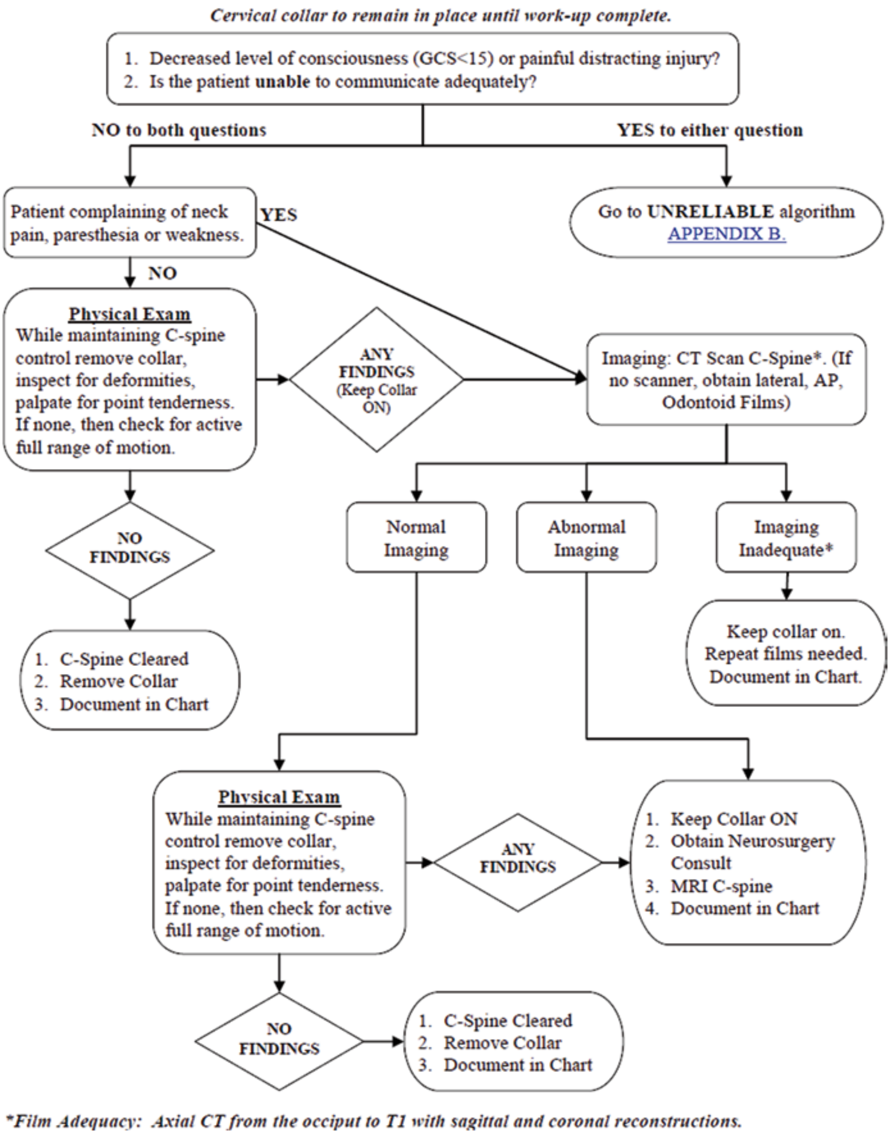

Fig. 13.5 Cervical spine clearance algorithm in a patient with clinically reliable exam. *CT* computed tomography, *MRI* magnetic resonance imaging, *GCS* Glasgow Coma Scale, *AP* anteroposterior. (Taken from [49])

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

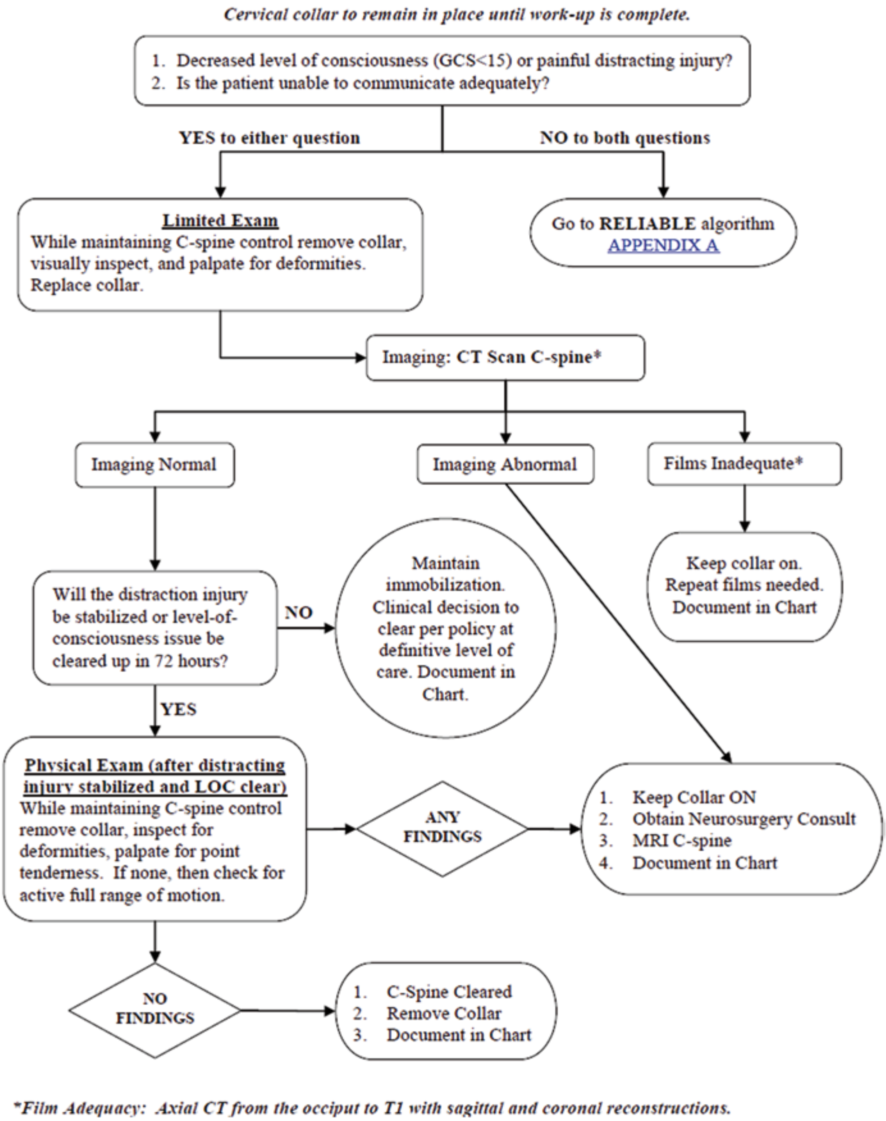

Fig. 13.6 Cervical spine clearance algorithm in a patient with an unreliable physical exam. *CT* computed tomography, *MRI* magnetic resonance imaging , *GCS* Glasgow Coma Scale, *LOC* loss of consciousness. (Taken from [49])

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.

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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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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 nonmodifiable) 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
Step 1: 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	*Step 1:* Identify and assess hazards
Step 2: 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	*Step 2:* Determine risk (loss severity and probability)
Step 3: 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	*Step 3:* Develop risk reduction controls
Step 4: 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	*Step 4:* Make risk acceptance decisions
Step 5: 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	*Step 5:* 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])

	Air Force		Army[a]		Marine Corps		Navy	
Cause of injury	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 (TRIPP) 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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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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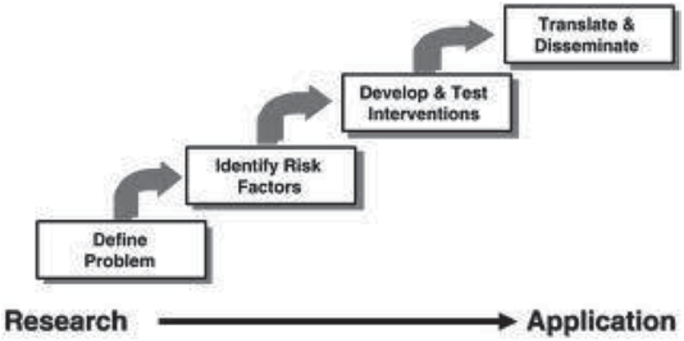


Fig. 15.1 Traditional four-step model of injury prevention

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 *(n)*	Total run distance (km)	Stress fracture incidence (*n*/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 % (χ^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-

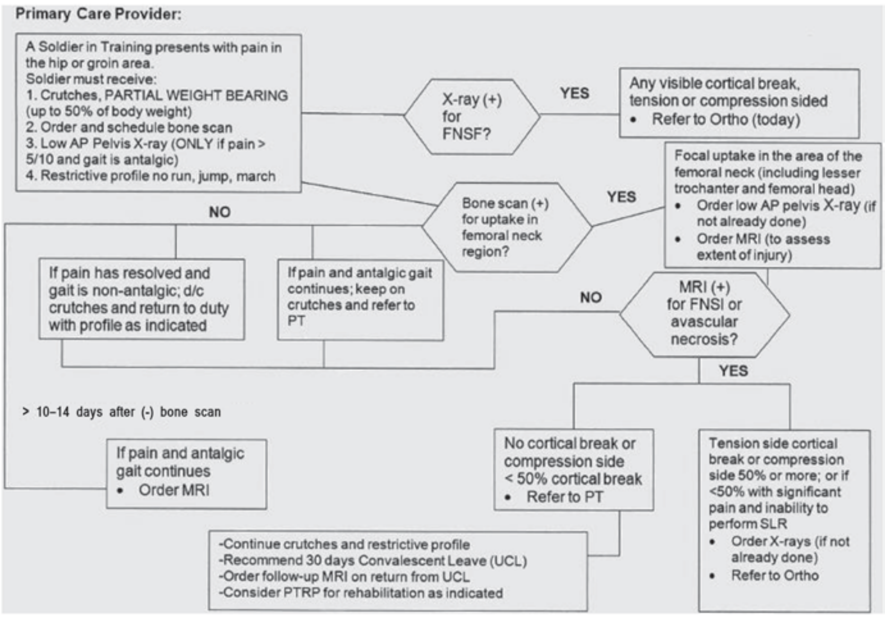


Fig. 15.2 Clinical management guidelines for hip pain at Fort Jackson, SC

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

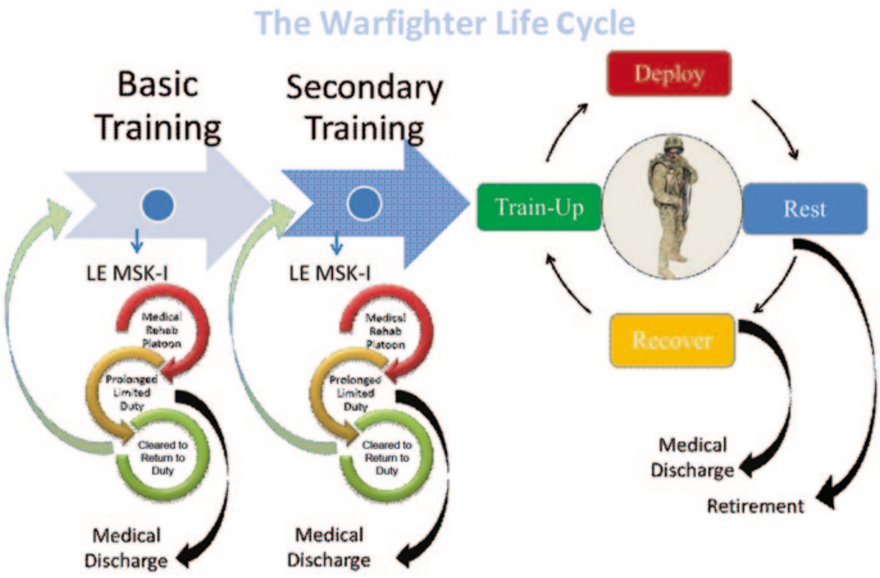


Fig. 15.3 Modern day war fighter life cycle

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)

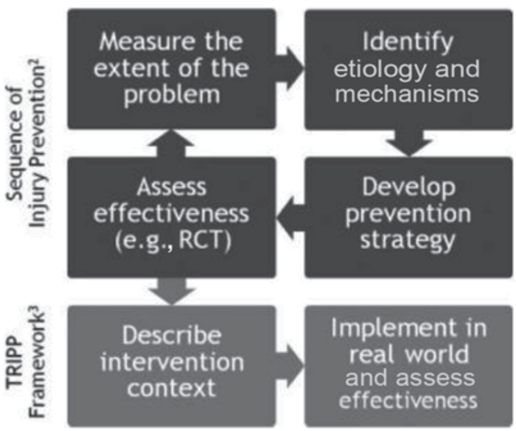
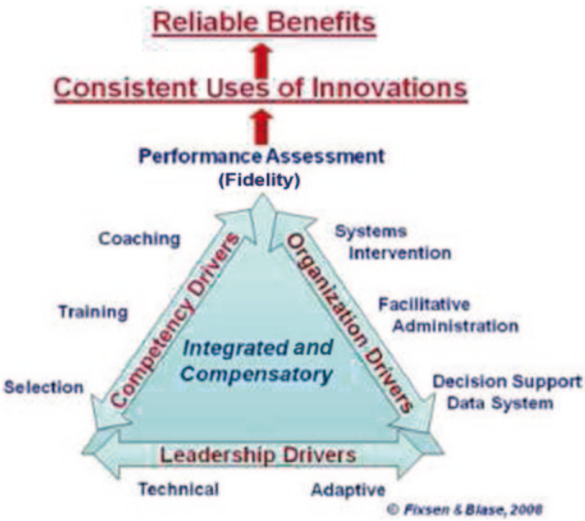


Fig. 15.4 Systematic approach to sports injury prevention

[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.

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Chapter 16
Overcoming Barriers to Injury Prevention in the Military

Deydre S. Teyhen, Stephen L. Goffar, Timothy L. Pendergrass, 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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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

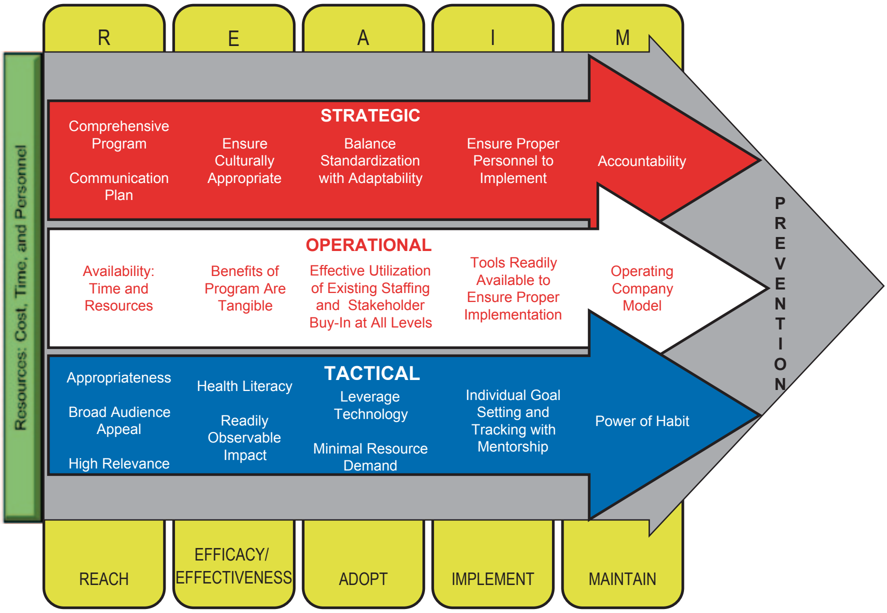

Fig. 16.1 Application of RE-AIM model to overcoming barriers to injury prevention in the military setting

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 number/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 e*ffectiveness* 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/MOEs may lead to an effective program being cancelled. Demonstrating prevention over time is a challenge. Appropriate MOPs/MOEs 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/MOEs 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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Index

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