

Chapter 2

Traumatic Combat Injuries

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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at greater risk of sustaining more than one musculoskeletal injury per casualty-inducing event (Schoenfeld et al., unpublished data) with incidence rates of multisystem orthopedic trauma (e.g., axial skeleton and extremities) exceeding 50 % in the most severely wounded personnel [9].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].

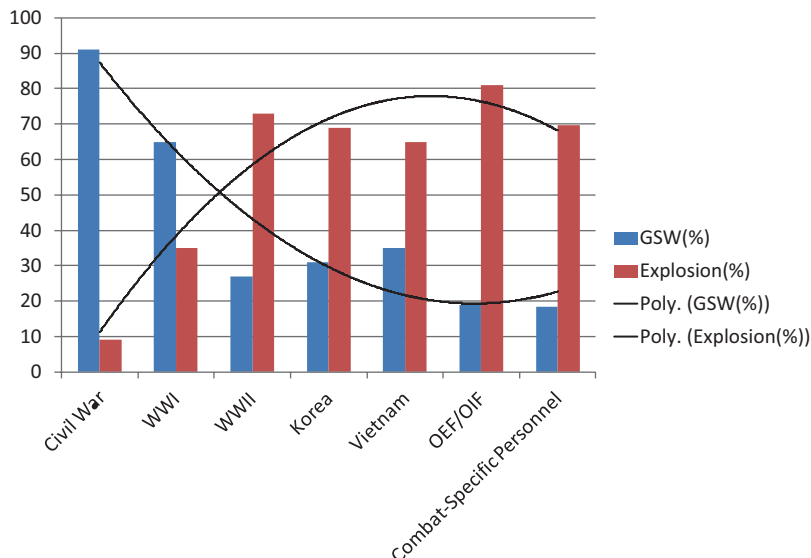


Fig. 2.1 Historical comparison of wounding patterns by conflict for major military engagements of the USA from the Civil War (1861–1865) to the present. Data for combat-specific personnel are derived from the Iraq and Afghanistan conflicts as reported by Schoenfeld et al. [19]. *WWI* World War I, *WWII*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

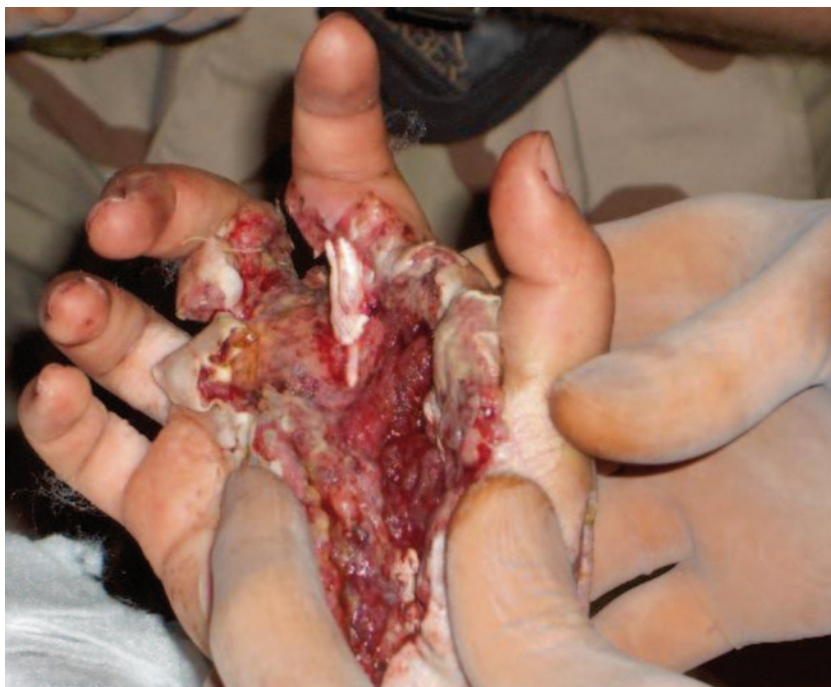


Fig. 2.5 High-velocity gunshot wound to the hand sustained by a soldier in Iraq

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 \times percent disability) [4].

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

Conclusions: Current State and Opportunities for the Future

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

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