Clinical Reviews in Bone and Mineral Metabolism (2018) 16:103–115
https://doi.org/10.1007/s12018-018-9252-1

FRACTURE

Military Fractures: Overtraining, Accidents, Casualties, and Fragility

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Published online: 28 November 2018

Abstract
Fractures sustained by military personnel are prevalent and costly both in the lives of individual service members and in consideration of overall military readiness. Training, environment, and hazards change throughout and after a military career. During training, military recruits are susceptible to stress fractures through overtraining. In both non-deployed and deployed non-battle environments, the most likely cause of fractures to service members is through mechanisms regularly encountered in civilian environments, including motor vehicle accidents and falls. In combat environments, however, fractures are typically sustained through targeted violent mechanisms such as explosions and gunshot wounds that often cause injury leading to long-term disability. Bone fragility is the primary cause of fracture for veterans. Fractures in the military maintain an incidence rate and injury mechanism similar to that in the civilian population, with the exception to battlefield casualties, while contributing a similar burden to the work force through limiting sustainable activity and increasing costs associated with treatment and recovery from injury. Greatly influencing the impact of fractures in the military is the mechanism of injury and the environment in which they are sustained.

Keywords Fracture · Combat injury · Military fracture · Stress fracture · Veteran injury

Introduction

Bone fractures pose a significant burden of injury in both civilian and military sectors [1, 2]. Interestingly and expectedly, many of the fractures sustained by military personnel share similarities with the normal civilian population, mainly the activity, environment, and health status of the service member greatly influences the type of bone fractures. Stress fractures are common in the military training population and are responsible for a substantial portion of limited duty days in the military [3]. Combat-related fractures sustained during deployment often present very different injury patterns than those sustained in civilian settings [4]. Many of these injuries are caused by explosives, resulting in much more severe and widespread damage than any mechanism of injury regularly encountered in non-combat environments [5–7]. Also, injuries caused by blasts in combat typically lead to complications that can persist and cause long-term pain and disability, thereby contributing to an aging veteran population that is susceptible to repeat fractures and further complications following combat trauma [8, 9]. In the same way that injuries are encountered in civilian occupational settings, the fractures sustained by military personnel are reflective of the physical demands and dangers of their environment as it changes throughout their careers, from basic training stateside to deployment in a combat environment to retirement (Fig. 1).

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General Burden of Fractures in the Civilian Population

Fractures comprise 9% of all occupational injuries, are responsible for more days lost from work than any other injury, and represent the most costly type of musculoskeletal injury overall [10]. Musculoskeletal injuries accounted for two thirds of the more than $123 million total cost of inpatient hospital care for injuries in 2011, with fractures contributing 72% of those musculoskeletal injury charges and nearly one half of all injury charges [1]. In the civilian workforce, fractures and

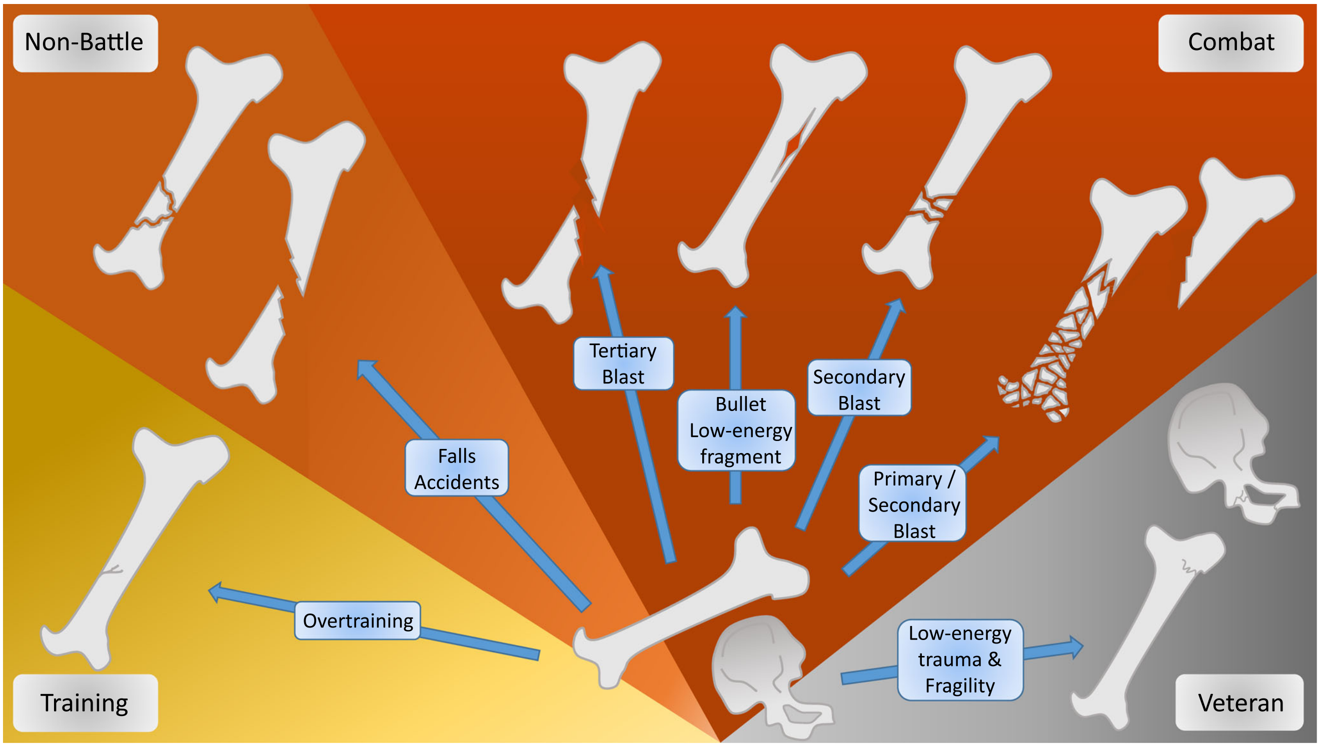

Fig. 1 Generalized overview of common fractures sustained during the different phases of military training, career, and retirement. During training, stress fractures are the most common among service members and present as cracks in bone tissue caused by overuse. Fractures sustained in non-battle environments are often caused by falls and accidents and can present as simple, comminuted, or compound fractures depending on the mechanism and force applied to the bone. Fractures sustained in combat environments range from simple fractures from falls caused by tertiary blasts to highly comminuted fractures and traumatic amputations caused by secondary and combined primary-secondary blasts, which are typical presentations of injuries sustained by both mounted and dismounted soldiers. Due to these injury mechanisms, the majority of the battlefield fractures are open. Fractures sustained by veterans commonly result from bone fragility due to pathological bone mineral density loss, with many fractures occurring at or near joints, and often presenting at the acetabulum

multiple injuries with fractures had a combined incidence rate of less than 9 per 10,000 full-time workers, but accounted for a median of 32 and 43 days away from work, respectively, compared to the median 9 days of missed work due to all nonfatal injuries and illnesses, making fractures the most severe occupational injury reported in 2016 [11].

Injuries among men are known to comprise the majority of fractures sustained in young adulthood, making up approximately two thirds of all fractures in that age group. Men reach their peak fracture rate at around 20 years old, at which age the majority of fractures sustained are through high-energy traumatic mechanisms. As the population ages, the trend eventually reverses, with men making up only one third of all fractures in late adulthood, and women reaching their highest fracture rate at approximately 85 years old, at which age fractures are primarily caused by low-energy trauma combined with bone fragility [12, 13]. Discrepancies in fracture risk between sexes have been attributed to differences in bone accretion and loss rates, type and intensity of activity sustained, body mass index (BMI) with higher BMI shown to be protective, and bone mineral density (BMD) as well as specific nutritional factors, with low BMD as the most predictive of fracture incidence [14–16].

Peak bone mass, bone accretion rates, and bone loss rates differ between women and men. As higher peak bone density heavily reduces the risk of osteoporosis in the future, these are all important determinants of bone health, particularly in the aging population most susceptible to bone fragility. In all healthy individuals, more bone is deposited than resorbed until age 30, at which point they have reached peak bone mass. Women reach 90% of their peak bone mass by age 18, while men acquire 90% of their ultimately greater peak bone mass around age 20. [16]. Several factors influence peak bone mass, with genetic factors including gender and race reported to account for up to 75% of bone mass determination and environmental factors such as nutrition, hormone levels, and lifestyle behaviors responsible for the remaining 25% [17]. In women, estrogen levels tend to correlate with bone strength, with age of menstruation as a strong indicator of bone mineral density [18]. Middle-aged men and women experience minimal change in total bone mass. However, quickly following menopause, most women experience rapid bone degeneration that eventually slows and continues throughout their lifetime, increasing their risk of developing osteoporosis [18]. It has been reported that women lose 35% of their cortical bone and 50% of their trabecular bone starting in their third decade, whereas men lose approximately two thirds of that amount over their entire lifetimes [19].

Fractures due to bone loss result in reduced life expectancy, prolonged medical care, and loss of independence, all of which ultimately lead to a substantial socioeconomic impact on the growing aging population [16, 20]. A recent study evaluating extremity fractures in women aged 65 and older reported post-fracture systemic bone loss leading to a likely increased risk in subsequent fracture in areas beyond the initial fracture site [21]. The results from this study present the need for further elucidation of the mechanisms leading to the perceived accelerated bone loss following fracture in order to reduce risk of subsequent injuries, particularly in the aging population that is far beyond peak bone mass and therefore more susceptible to recurrent fragility fractures.

Fractures are often under-appreciated in terms of the long-term costs and potentially life-long consequences they incur. As fractures both indicate and cause decreased bone strength, they are particularly incapacitating in the older population. In fact, 7% of those who sustain an osteoporotic fracture in the USA acquire some permanent disability, with 8% requiring long-term nursing care [22]. It is important to take into account disability, loss of productive years, and quality of life when considering the impact of these injuries.

Military Training Injuries

Injuries sustained in military training, whether prior to or during deployment, are most often due to overtraining and overuse. Much effort is put in from the military to ensure that service members are physically fit before they are deployed, but either because of overtraining on the part of the military, under-preparedness on the part of the soldier, or a combination of these and other factors, they are often stressed to the point of injury. While military officer candidates matriculate and train in Officer Candidate School training programs or military academies, enlisted recruits go to basic training. During this training, there is often a sharp increase in the physical demand experienced by trainees as they are compelled to achieve a level of fitness required for deployment, sometimes immediately from backgrounds of very low activity. Though many factors determine injury risk in this population, those with low pre-training fitness levels are more susceptible to sustaining injuries during military training [23, 24]. The steep incline in the level of stress on these trainees' bodies in the short amount of time translates to a rapid introduction to repetitive successions of mechanical loading on those tissues, often resulting in bone strain [25]. The accumulation of this damage eventually leads to the development of stress fractures in a substantial number of military recruits. The incidence rate of stress fractures has been reported as 3.5 to 8.5% in U.S. military recruits undergoing basic training, and 3.6 to 31% in the Israeli military [25–27]. In female U.S. Navy military recruits, the rate may be as high as 21% [28]. A study evaluating determinants of stress fractures in cadets at the U.S. Military Academy reported an incidence of 5.7% and 19.1% in male and female cadets, respectively [29]. In the cases of more severe injuries, trainees may be medically discharged or given restricted duties before their first deployment, thereby weakening the fighting force as well as depleting military resources [30]. Just as the training military population maintains a higher stress fracture rate than the rest of the military, track and field athletes represent a subpopulation that is heavily affected by stress fractures in the civilian setting, with reports of up to 52% of runners having a history of stress fracture and one year-long prospective study reporting a 21% incidence rate of stress fractures in a group of track and field athletes [31, 32].

Typically, the bone remodeling process is able to prevent the damaging effects that stress can have on bone tissue, but if there is not enough time to repair the injury before more damage is done, stress fractures occur. In healthy tissue, that microdamage acts as a stimulator for the remodeling process, but when combined with the constant repetition of intense exercises that make up training along with fatigued muscles that fail to act as protective shock absorbers, the system falls behind as the osteoblastic reformation process works to catch up with the resorptive osteoclast activity. This results in decreased bone tissue that is unable to compensate for the accumulation of microdamage, ultimately leading to stress fractures [25, 33]. This is often seen in these military training programs, where inexperienced trainees are tasked with repeated exercises over non-compliant, uneven surfaces in new footwear. Those unacquainted with this type of strenuous activity can quickly become injured.

There are many well-established factors that contribute to the development of stress fractures. Extrinsic factors such as changes in training regimen, equipment utilized, and type of activity and terrain endured all play a part in the degeneration of bone tissue seen in these injuries [25]. Some of these components are adjustable so as to prevent some of these injuries from occurring, as in reducing the number of miles marched during training, or slowing the intensity buildup of the training regimen. However, there may be drawbacks to lengthening basic training in order to compensate for intensity-influenced injuries, namely the costs may outweigh the benefit of a longer basic training period. Proper preparation before training begins is a good start in preventing these injuries, though adherence to a preparatory training regimen is difficult to regulate or uphold among recruits before they begin official training [25].

Gender, physical fitness, age, and bone density are some intrinsic factors that have been implicated in the formation of stress fractures. These injuries disproportionally affect female military recruits, with the components of the female athlete triad heavily influencing the higher injury rate [28, 34]. Individual determinants within the female athlete triad include oligomenorrhea or amenorrhea, osteoporosis, and energy deficit with or without disordered eating [34, 35]. Several studies describing stress fracture rates in female military training populations have identified these components as risk factors [36, 37]. Stress fractures during military training are most common in the lower extremities, which is likely attributable to the emphasis on enforced running and marching activities [28, 38–40]. Consistent with data from other military services, one study describing injuries during Air Force basic training reported an increased injury risk in soldiers aged 27 and older compared with younger soldiers [39, 41, 42]. However, studies on active duty infantry and other operational units have shown that increasing age correlates with a lower injury incidence among soldiers, with exception to Special Forces where older age was found to be a risk factor for musculoskeletal injuries [43]. This may be due to differences in activity sustained by older military personnel during active duty, as older personnel typically have a higher rank and managerial jobs that are less physically demanding, whereas in basic training, all recruits are required to perform the same exercises, regardless of age [43].

As treatment for stress fractures essentially consists of rest allowing for the bone to heal itself, stress fractures pose a problem in the training military population by limiting the amount of activity and training that injured recruits can endure. They are also responsible for a substantial contribution to early attrition from service [44]. It has been reported that 40% of men and 60% of women who sustain a stress fracture fail to complete basic training; thus, stress fractures have a substantial impact on military readiness [28]. Stress fractures represent just one example of preventable injuries that are prevalent in the military and cause a great burden on the fighting force. It is important that modifiable risk factors are identified and attenuated in order to avoid as many of these injuries as possible.

Non-battle-Related Injuries in Active Duty Military

Non-battle injuries, which consist of all of those resulting from circumstances not directly attributable to hostile action or terrorist activity, are primarily due to accidents and constitute the military injuries that are most analogous to injuries sustained in civilian environments. The leading causes of non-battle injuries in Iraq and Afghanistan during Operation Iraqi Freedom and Operation Enduring Freedom were sports activities and physical training, falls and jumps, and military vehicle accidents. This is similar to common mechanisms of injury for occupational injuries in the civilian workforce within the same period, in which falls, overexertion, and motor vehicle accidents contributed to a large portion of reported injuries [45, 46].

From 2001 to 2013, non-battle injuries accounted for one third of all air evacuations of U.S. Army soldiers from Afghanistan and Iraq, nearly twice as many as evacuations for battlefield injuries during the same period [28]. Fracture was the leading type of injury and accounted for 21% of non-battle injury evacuations [45]. Though combat injuries are often given more attention than non-battle injuries in consideration of their impact on military costs and effectiveness, non-battle injuries pose a greater challenge in the way of overall force readiness [47, 48]. Compared to past wars, the recent operations in the Middle East have seen a decrease in the ratio of non-battle injuries and disease to combat casualties, but non-battle injuries still maintain a higher prevalence over combat-related injuries and require greater resource utilization [49].

Injuries affect a large number of non-deployed service members as well. In the period from 2008 to 2017, there were more than 3.5 million injuries among active duty, non-deployed U.S. service members [33]. Fractures are the leading injury type requiring hospitalization among non-deployed U.S. service members, comprising 40% of all injuries that require hospitalization. Overall, fractures have accounted for 10.5% of injuries to non-deployed service members, with the majority occurring in the hand or wrist and foot or ankle [50]. Unlike the rate for deployed combat troops, the military fracture rate for non-deployed service members is not disproportionally high compared to the fracture rate in the USA as a whole, and the resulting burden reflects that of civilian injuries [51]. A descriptive table of selected studies on non-battle fractures can be found in Table 1.

In the same way that occupational hazards vary among different civilian jobs, some work-related activities within the military have a higher incidence of musculoskeletal injuries than others. This is evidenced by differences in injury patterns reported in various deployed units, and even in injury rates among ranks within the same unit [43]. One study reported a fracture rate three times higher in deployed construction engineers than in combat artillery soldiers within the same one-year period [59]. There are also differences in injury incidence among deployed reserve, guard, and active duty personnel, with active duty personnel maintaining the highest fracture risk among all components and higher ranking personnel within each component maintaining lower rates of non-battle injuries [47]. In the evaluation of a U.S. Army brigade combat team, almost all non-combat fractures were sustained by enlisted soldiers, with an incidence of zero in senior officers, suggesting that injury risk depends heavily on one's position and job description in the military. In fact, enlisted and non-commissioned officers sustained 94% of all disease and non-battle injuries [54]. These different injury rates also show

Table 1 Non-battle fractures sustained during recent U.S. conflicts

Study	Time period	Location	Population	Injury type/location	Combat injuries	Non-battle injuries	No. of fractures	% Fractures of reported injuries	% Open	Most common MOI of all injuries	Most common fracture
Zouris et al. [52]	2003–2005	Iraq	U.S. Army U.S. Marine Corps	All injuries	X	X	775	33.5	NR	NR	NR
Jones et al. [51]	2000–2006	USA	All non-deployed U.S. service members	All injuries		X	56,126	10.2	NR	Miscellaneous other, NR (16.8%) Nonmilitary vehicle accidents (15.4%)	Wrist, hand, fingers
Hauret et al. [53]	2001–2006	Iraq	U.S. Army	All injuries		X	1778	35.3	NR	Sports/physical training	Lower leg, ankle
Eaton et al. [47]	2001–2006	Iraq Afghanistan	U.S. Air Force	All injuries		X	655	4.8	NR	NR	NR
Patel et al. [45]	2001–2013	Iraq Afghanistan	U.S. Army	All injuries		X	4695	21	NR	Sports/physical training Falls/jumps	Lower leg, ankle (34.3%) Wrist, hand (28.3%)
Stahlman et al. [50]	2008–2017	USA	All non-deployed U.S. service members	All acute (non-overuse) injuries		X	387,016	10.5	NR	Undocumented or undetermined causes (69.7%)	Hand, wrist (21.3%) Foot, ankle (14.6%)
Belmont et al. [54]	NR	Iraq	U.S. Army brigade combat team	Musculoskeletal injuries		X	66	9.9	NR	NR	NR
Mathieu et al. [55]	2009–2013	Afghanistan	All injured patients receiving surgery at KaIA CHS	Upper extremity injuries	X	X	138	52.3	29	Heavy work/machinery (41.7%) Fall or accident at home (32.8%)	NR
Blair et al. [56]	2001–2009	Iraq Afghanistan	All U.S. service members	Spine injuries	X	X	241	90	NR	Motor vehicle collisions (54%) Falls (30%)	Lumbar spine
Wade et al. [57]	2004	Iraq	U.S. Navy U.S. Marine Corps	Head, face, and neck injuries	X	X	6	3.4	NR	Motor vehicle collisions (31%) Blunt trauma NOS (19%)	Face NOS
Madson et al. [58]	2001–2011	Iraq Afghanistan	All U.S. service members	Craniomaxillofacial injuries	X	X	484	29.5	NR	Motor vehicle collisions (37%) Falls (20%)	NR

MOI, mechanism of injury; *NR*, not reported; *NOS*, not otherwise specified that non-battle injuries are largely preventable and are generally caused by accidents including falls while maintaining physical fitness through sports and other activities, thus presenting the challenge of establishing an environment in which active duty personnel can both maintain the level of physical fitness required of combat troops while also avoiding injuries that so frequently occur in pursuit of that effort.

Combat-Related Injuries

Fractures sustained in combat largely result from trauma through intentional violence. Because the mechanisms and intensity of assault seen in modern warfare are unlike anything typically encountered in civilian settings, the resulting array of fractures sustained by military personnel in combat are generally much more severe than those experienced by their civilian counterparts. The broad movement away from symmetric battlefield tactics toward unconventional insurgent attacks utilizing homemade explosive devices in recent conflicts has also facilitated a shift toward more debilitating orthopedic injuries in combat casualties, not the least of which include complex axial and appendicular fractures and traumatic multiple-limb amputations [7, 49, 60]. Improvised explosive devices and explosively formed projectiles have been found responsible for the majority of all combat injuries [5, 61]. As these explosives are often aimed at maiming rather than killing their targets, casualties of this weaponry often survive with devastating orthopedic injuries and subsequent disabilities [7].

These blast mechanisms take on many forms including anti-personnel mines primarily causing severe lower limb injury to dismounted soldiers and anti-vehicle mines which are responsible for the vast majority of vehicles lost in wartime [62, 63]. The various explosive types within this broad mechanism category cause a wide spectrum of injuries, ranging from concussion to traumatic amputation [64]. Several factors that influence the types of injury sustained from blasts include the distance of the individual from the explosive, presence of a physical barrier, and protective equipment utilized by the individual. Primary blast injuries result from the energy transfer of the blast wave directly on skeletal structures, which can cause traumatic limb amputation and most often result in death [65]. These injuries are most often sustained in open environments. Secondary blast injuries are caused by penetrating trauma from explosive blasts, usually in the form of bomb casings or debris implanted within the explosive. Fractures produced by this mechanism are similar to those caused by gunshot and are typically highly comminuted and contaminated with external debris, often corresponding to persistent infection after treatment, with the degree of comminution proportional to the energy of the penetrating fragment [66]. High-energy fragments can also cause fractures indirectly by passing by the bone in close proximity, usually resulting in simple fractures with little to no bone fragmenting. Mixed primary and secondary blast injuries are often sustained by dismounted soldiers when they encounter an anti-personnel mine. Detonation of the explosive causes immediate shattering of the bone and soft tissue of the distal limb, usually affecting the lower limb including the tibia and fibula as the device is stepped on, sometimes resulting in traumatic amputation or the need for surgical amputation later on in theater. As the first responding service members on the ground, U.S. Marines have been disproportionately exposed to these dismounted complex blast injuries, with a reported fourfold increase in risk compared to other services as well as an increased risk of sustaining multiple amputations [60, 67, 68]. Tertiary blast injuries, which comprise the majority of blast injuries sustained in enclosed spaces often while mounted in a motor vehicle, result from the direct impact of the individual against solid structures. The fractures sustained through this mechanism are similar to civilian blunt trauma injuries, with the level of bone splintering also dependent on the force of impact [7].

Musculoskeletal injuries have been found to comprise a majority of all combat casualties sustained by U.S. service members in Iraq and Afghanistan, with fractures making up 40% of all musculoskeletal injuries during the peak of the wars from 2005 to 2009 and the majority of those fractures classified as open. Most musculoskeletal casualties sustained at least one fracture, and 82% of all musculoskeletal injuries resulted from an explosive blast, with only 14% caused by gunshot [6]. Another study from a British field hospital [69] found that open wounds and fractures accounted for 74% of injuries to survivors of hostile action in Iraq, with explosive devices causing the majority of injuries among casualties. A description of selected studies on combat fractures can be found in Table 2. These devastating injuries have become largely survivable following the implementation of advanced personal protective equipment (PPE), frontline damage control practices, and rapid evacuation procedures [77]. PPE typically consists of protective armor primarily covering the head and torso of the soldier, leaving the extremities, especially the lower extremities, relatively susceptible in these attacks and the most impacted by blast mechanisms [55, 77, 78].

Combat orthopedic extremity injuries are the most frequent cause of rehospitalization and utilize the most resources during rehospitalization, with fracture nonunion and infection as the most common reasons for readmission [79]. In a study specifically describing extremity combat wounds sustained in these conflicts, fractures comprised more than a quarter of all battlefield extremity injuries. Eighty-two percent of all fractures sustained in combat were classified as open, and explosions were found to be the mechanism of injury in 75% of all extremity injuries [73]. Given the high rates of these injuries along with reports that the majority of soldiers with a primary diagnosis of extremity injury are ultimately found unfit for continued service, extremity fracture wounds

Table 2 Fractures sustained in combat during recent U.S. conflicts

Study	Time period	Location	Population	Injury type/location	Combat injuries	Non-battle injuries	No. of fractures	% Fractures of reported injuries	Incidence rate	% Open	Most common MOI of all injuries	Most common fracture	Most common open fracture
Zouris et al. [70]	2003	Iraq	U.S. Marines (97%) U.S. Navy (3%)	All injuries	X		109	17.7	NR	NR	Explosions (46%)	NR	NR
Ramasamy et al. [69]	2006	Iraq	All combat casualties presenting to BMFHS	All injuries	X		34	14	NR	NR	Explosions (54%)	NR	NR
Zouris et al. [52]	2003–2005	Iraq	U.S. Army U.S. Marine Corps	All injuries	X	X	956	29.3	NR	NR	NR	NR	NR
Belmont et al. [71]	2006–2007	Iraq	U.S. Army brigade combat team	Musculoskeletal injuries	X		59	24	11.4 per 1000 combat--years	44	Explosions (80.7%)	Tibia (17%)	Tibia
Belmont et al. [6]	2005–2009	Iraq Afghanistan	All U.S. service members	Musculoskeletal injuries	X		6794	40	3.4 per 1000 combat--years	57.9	Explosions (74.9%)	Tibia/fibula (17%) Hand (14%)	Tibia/Fibula
Lin et al. [72]	2001–2003	Afghanistan	U.S. service members and Afghan nationals treated at Walter Reed	Orthopedic injuries	X		49	50	NR	28.6	Fragmentation from landmines or ordinance (65%)	Hand (22%)	NR
Owens et al. [73]	2001–2005	Iraq Afghanistan	All U.S. service members	Extremity injuries	X		915	26	NR	82	Explosions (75%)	Tibia/fibula (24%)	NR
Dougherty et al. [74]	2004–2005	Iraq	U.S. Navy U.S. Marine Corps	Extremity injuries	X		316	19.1	NR	NR	IED (37.1%) Gunshot (20.5%)	NR	NR
Mathieu et al. [55]	2009–2013	Afghanistan	All injured patients receiving surgery at KaIA CHS	Upper extremity injuries	X	X	113	38.4	NR	95	Fragment (41.4%) Gunshot (29.9%) IED and other blasts (23.8%)	NR	NR
Schoenfeld et al. [60]	2003–2011	Iraq Afghanistan	U.S. Army Cavalry Scouts	Pelvic, spinal, and extremity injuries	X		1020	65	NR	NR	Explosions (69%)	Tibia (13%)	NR
Blair et al. [56]	2001–2009	Iraq Afghanistan	All U.S. service members	Spine injuries	X	X	1687	92	NR	NR	Explosions (66.7%)	Lumbar spine	NR
Wade et al. [57]	2004	Iraq	U.S. Navy U.S. Marine Corps	Head, face, and neck injuries	X	X	96	12.4	NR	NR	IED (64%)	Face NOS	NR

Table 2 (continued)

Study	Time period	Location	Population	Injury type/location	Combat injuries	Non-battle injuries	No. of fractures	% Fractures of reported injuries	Incidence rate	% Open	Most common MOI of all injuries	Most common fracture	Most common open fracture
Lew et al. [75]	2001–2007	Iraq Afghanistan	All U.S. service members	Craniomaxillofacial injuries	X		1280	27	NR	76	Explosions (84%)	Mandible (36%)	Mandible
Chan et al. [76]	2001–2011	Iraq Afghanistan	All U.S. service members	Craniomaxillofacial injuries	X		1779	44.1	NR	75	Explosions (88.6%)	Other facial NOS Zygomatic/maxilla	Other facial NOS
Madson et al. [58]	2001–2011	Iraq Afghanistan	All U.S. service members	Craniomaxillofacial injuries	X	X	1266	24.9	NR	NR	Explosions (88%)	NR	NR

MOI, mechanism of injury; *NR*, not reported; *NOS*, not otherwise specified

comprise a large burden of combat casualties in modern conflicts [80].

The open calcaneus fracture sustained through blast mechanisms presents an injury pattern unique to the combat environment. Up until modern conflicts, combat calcaneus fractures largely resembled those sustained in civilian settings, with falls from great heights as the most common mechanism of injury. In recent wars and ongoing conflicts, these injuries are frequently caused by high-energy explosions targeted at both mounted and dismounted soldiers. These fractures are typically highly fragmented and massively contaminated with debris in an "outside in" mechanism of soft tissue damage, creating comminution so severe that the joint is often deemed irreparable [81–83]. Otherwise known as "deck-slap" injuries, these wounds often result in delayed amputation or salvage with poor long-term functionality. It has been noted that most patients who sustain a combat open calcaneal fracture requiring flap coverage eventually opt to amputate due to non-function and persistent infection [82, 84]. Although calcaneal fractures are rare both in civilian and combat environments, they are much more prevalent and generally more damaging injuries in combat. In fact, several fractures that are rarely seen in civilian settings are far more common in combat. Scapula fractures, for example, have a 20 times higher incidence rate in combat military personnel than in the civilian population due to the massive amount of energy required to produce this injury [85].

Along with the high prevalence of combat extremity wounds, military personnel in Iraq and Afghanistan have also endured a higher incidence of traumatic spine injuries compared with previous conflicts. Five percent of combat casualties evacuated from 2001 to 2009 sustained at least one spinal injury, with explosions accounting for most of those injuries. Fractures comprised the vast majority of all spine injuries, with transverse process, compression, and burst fractures the most common injuries overall [86]. One study analyzing injuries sustained by U.S. service members killed in Iraq and Afghanistan determined that spinal trauma was present in 40% of those killed, with explosions as the mechanism for most injuries and fractures making up almost 75% of all spinal injuries [87]. Combat spine fractures are also likely to present with multiple associated injuries. Another study found that 78% of casualties with a combat spine fracture sustained at least one concomitant injury, with additional musculoskeletal injuries comprising the majority of associated injuries and the pelvis as the most commonly co-injured area [88].

The pelvic blast injury with open fracture represents one of the most severe wound patterns encountered by the military trauma surgeon. This injury is generally indicative of multisystem trauma as it is often concomitant with extensive urological damage and traumatic bilateral femoral amputation. Of 89 survivors of combat open pelvic fractures reported in one study, only one sustained the pelvic fracture as an isolated injury. Because of the extensive damage and great opportunity for infection, these injuries are highly prone to complications and poor recovery [89].

Overall, open wounds comprise the majority of all combat injuries, with open fractures making up 44–82% of all combat fractures [71, 73]. One of the most difficult obstacles facing military medics and surgeons in treating open fractures in the combat theater is the high rate of complications due to infection seen in these injuries. In one study of combat open tibial fractures, infection alone was significantly associated with poor bony healing [90]. Because of the immediate exposure of soft tissue to dirt and debris in the combat environment, the comminuted nature of fractures secondary to blast injuries, and the necessary delay of definitive treatment, the risk of infection and further complications is much higher in open fractures sustained on the battlefield than in non-combat environments [91–93]. In a study comparing combat and civilian open tibia fractures, a huge difference in mechanism of injury was reported, with motor vehicle accidents responsible for the majority of civilian injuries and improvised explosives as the predominant mechanism of injury for combat fractures. The more severe combat mechanisms resulted in more extensive injuries and a higher rate of amputation in the military group than in the civilian group, with 18% (21/115) of combat open fractures and only 5% (45/850) of civilian open fractures resulting in amputation [4]. For more proximal injuries affecting the popliteal artery, the rate of secondary amputation was 29% for combat casualties versus 13% in civilians [94]. The current standard of treatment for preventing infection in combat open fracture wounds includes early administration of antibiotics, irrigation and debridement, temporary external fixation, and delayed primary closure [95–97]. There are many opportunities for better therapies for these injuries.

Orthopedic injuries from combat cause the majority of long-term disabilities in service members, with fractures as the second most common injury resulting in unfitting conditions [98]. The higher rates of infection, poor bone healing, nonunion, and late amputation associated with open fractures sustained through combat mechanisms lead to longer recovery times, loss of functionality, greater financial costs, and long-term disability in many service members [83, 92, 99–101]. The overwhelming presence of these injuries has necessitated an increased emphasis on limb salvage in combat theater [102]. In order to produce the most favorable outcomes possible in combat casualties requiring limb salvage, it is important that frontline surgeons are able to reliably predict the strategy that will result in the best long-term functionality, whether that means salvage or amputation of mangled limbs [103–105]. As fit, young, enlisted men comprise the vast majority of combat casualties, they are often healthy, motivated to return to duty, and willing to put in great effort to recover from and adjust to these life-altering injuries [73, 106]. However, complications following combat trauma lead to a low return to duty rate for these casualties, substantially lowering the quality of life for many service members [107–109]. The relatively young age and good health of this population also mean that the already drastic morbidity of these injuries is even more pronounced in these individuals because of the number of years lived with disability due to the injuries they have sustained on the battlefield. Between 2001 and 2009, there was an 88% increase in the number of soldiers medically separated or retired and a 67% increase in the number of unfitting conditions per soldier, the most common of which were orthopedic [110]. From 2005 to 2011, the overall rates of disability evaluation decreased, while rates of disability retirement increased, reflecting an increase in severity of the disabilities evaluated [111]. These changes have led to a greater financial burden on the Department of Veteran Affairs through increasing the need for expenditure on readjustment benefits and vocational rehabilitation for young injured service members as well as physical rehabilitation from combat orthopedic injuries [110, 112].

Veteran Injuries

Fractures sustained by veterans are most commonly due to bone fragility [113]. Some of this fragility may be due to injuries sustained during their military careers, whether from stress injuries during basic training or traumatic combat injuries, while some is simply due to the steady degeneration of bone tissue that occurs throughout one's lifetime. Fractures, especially those sustained through traumatic blast mechanisms, can have enormous implications for those casualties long after retirement from the military. Aging veterans with these injuries encounter numerous bone health issues at greater rates than the civilian population [9]. With the increasing severity and energy of trauma, there is an increase in the risk of complications including osteomyelitis, nonunion, delayed amputation, posttraumatic osteoarthritis, and heterotopic ossification (HO) following injury [98, 101, 114]. In severe fractures resulting in mangled extremities requiring limb salvage or amputation, HO has become a common complication for combat veterans, with reports of up to 65% of military blast extremity injuries developing HO [9, 115]. Independent predictors of HO include multiple limb trauma, amputation, large wound surface area, high injury severity score, spinal cord injury, and high-energy mechanisms, all of which are common presentations in blast injuries [9]. This complication can lead to persistent pain, multiple revision surgeries, and further disability, while also disrupting the fitting and utilization of potentially beneficial orthotics and prosthetics [116–118].

Previous fractures in some areas, such as the pelvis, spine, and wrist, are well-recognized predictors of future fracture [119, 120]. Particularly in the older population commonly affected by osteoporosis, patients who sustain one fracture incur a greater risk of subsequent fracture [121]. One study reported that 40 to 60% of surviving women and men who sustained a non-traumatic fracture after age 60 experience a subsequent fracture, with the increased risk persisting for up to 10 years [122]. There is also an increased risk of mortality with both initial osteoporotic fracture and subsequent fracture, with absolute mortality rates dependent on the location of fracture [123]. Patients with nonunion are also more likely to sustain an additional fracture [124]. Considering the severity of injuries and conditions sustained by veterans retired due to being unfit for duty because of an orthopedic condition and the fact that combat military personnel are more likely to sustain multiple traumatic fractures than the civilian population, they are more susceptible to pain, complications, disability, and further injury following combat injury [79, 98, 110]. Veterans who sustain a combat spinal cord injury, in particular, display a disproportionately high incidence of subsequent appendicular and osteoporotic fractures [125, 126]. Therefore, not only do these service members incur disabilities from injuries sustained in combat but they are also likely to suffer subsequent injuries, especially when combined with loss of limb due to complications from combat-related fractures [117, 127].

Female military personnel comprise 16% of the enlisted forces and 18% of the officer corps [128]. With roughly 4% of active duty servicewomen in combat positions, they sustain fewer combat injuries overall than their male counterparts [129, 130] However, women are more likely to sustain stress fractures during military training (21% vs. 8.5%, respectively) and non-battle injuries requiring medical evacuation during deployment (115.7 vs. 33.9, respectively, per 1000 combat years) [54, 131]. The higher rate of previous injury in female service members, along with lower bone mineral density following menopause, results in a steep increase in fracture risk as they age [132]. Fifty-four percent of women are estimated to sustain at least one osteoporotic fracture after age 50 [22]. Furthermore, one study found a 74% increase in the risk of fractures after the age of 50 in women who sustained a non-traumatic fracture between the ages of 20 and 50 [133]. Considering the significant number of women who sustain stress fractures during military training, the higher rate of fracture predisposing factors observed in veteran compared to civilian women, and the expected increase in ratio of senior to younger veteran women, this could lead to an increase in the burden of osteoporotic fractures within this population [134–136]. Concurrently, there seems to be a deficit in the assessment and treatment of fracture patients in order to prevent repeat injuries [113, 137].

Conclusion

Fractures sustained by active duty military personnel are similar in overall prevalence to those sustained in civilian settings, and in both populations, they comprise a large burden of disease. The biggest difference between fractures seen in these populations is the mechanism of injury that is becoming increasingly more common in combat. Explosive mechanisms cause much greater and more extensive damage than any mechanism seen in civilian settings, and injuries from these mechanisms can lead to substantial complications further into the future, impacting veteran life. Also, as the borders of the modern battlefield expand or are blurred, more civilians may be exposed to those same injury patterns [116, 138]. The environments in which military personnel are placed throughout their career ultimately dictate the injuries they are likely to endure, and the severity of fractures sustained by individuals in the military are proportional to their exposure to the occupational hazards involved. The long-term impact of those fractures is essentially reflective of the environment, severity, and mechanism of injury. Further study and comparison of the injuries sustained by enlisted forces and officers, male and female military personnel, and within individual services will be valuable in optimally determining injury risk and prevention throughout the military.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Research Involving Human or Animal Participants The article does not contain any studies with human or animal subjects performed by any of the authors. Informed consent is not needed as no studies on human subjects were performed.

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