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 predeployment, 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

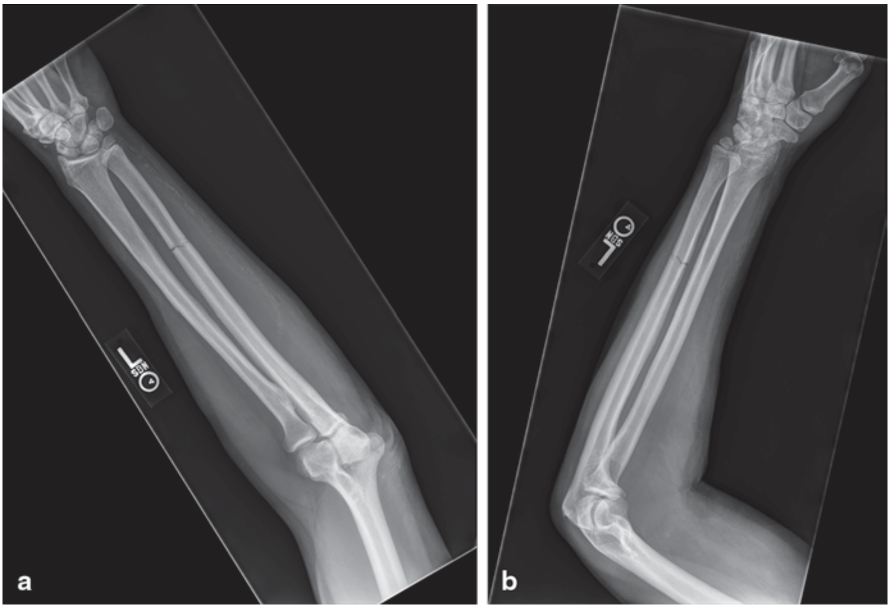

Fig. 8.1 **a** Posteroanterior and **b** lateral radiographs of the forearm with ulnar stress fracture

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

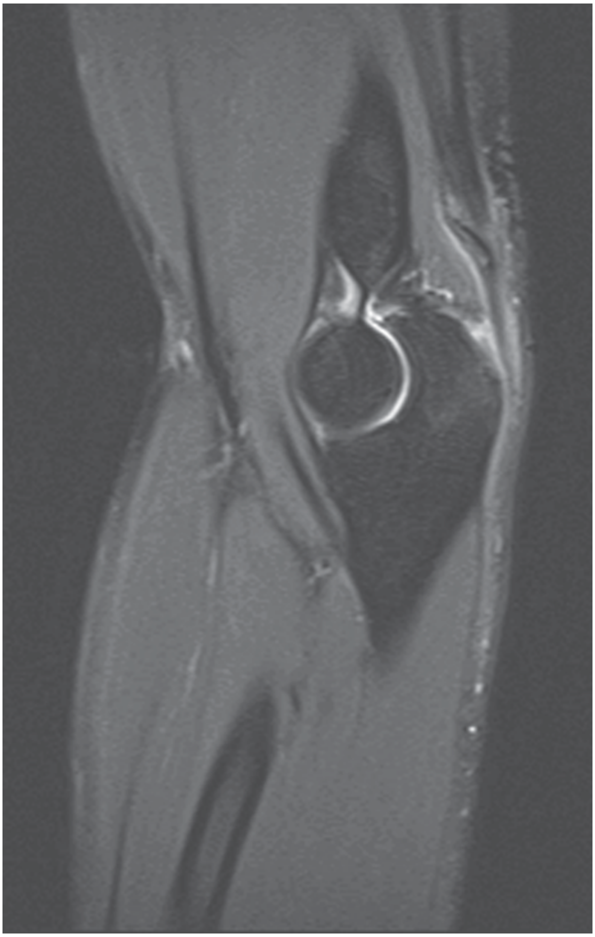

Fig. 8.2 MRI image of low-energy triceps rupture

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].

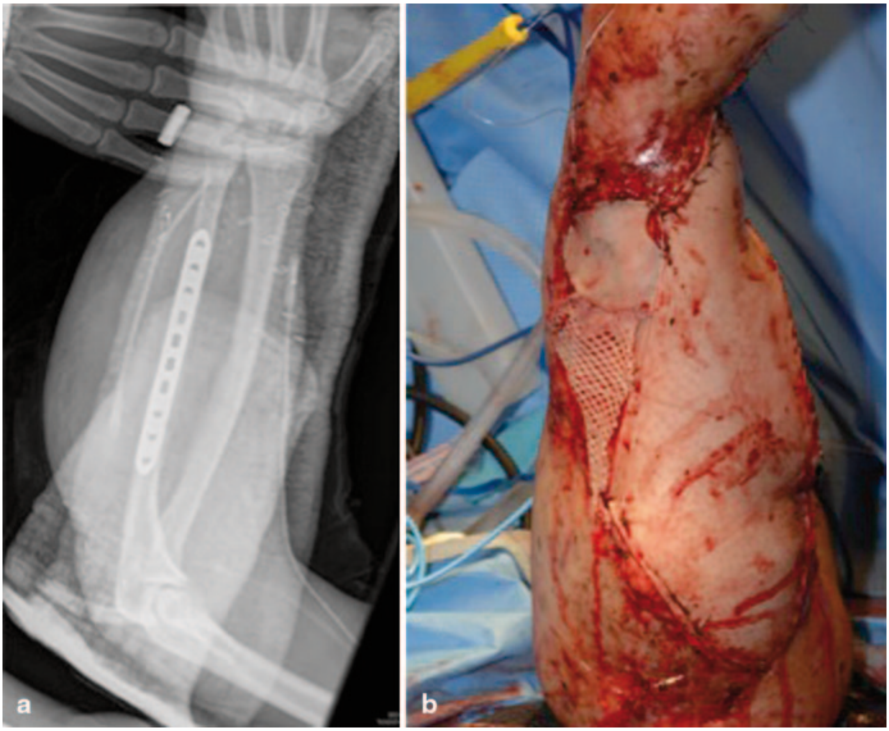

Fig. 8.4 After initial injury and battlefield tourniquet placement to his right upper and bilateral lower extremities, the patient was medically evacuated to the Role 3 medical facilities in Kandahar, Afghanistan, where an initial irrigation and debridement was performed on his right upper extremity.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