SCIENTIFIC ARTICLE

# The Scope and Distribution of Upper Extremity Nerve Injuries Associated With Combat-Related Extremity Limb Salvage

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**Purpose** Chronic pain and functional limitations secondary to nerve injuries are a major barrier to optimal recovery for patients following high-energy extremity trauma. Given the associated skeletal and soft tissue management challenges in the polytraumatized patient, concomitant nerve injuries may be overlooked or managed in delayed fashion. Whereas previous literature has reported rates of peripheral nerve injuries at <10% in the setting of high-energy extremity trauma, in our experience, the incidence of these injuries has been much higher. Thus, we sought to define the incidence, pain sequelae, and functional outcomes following upper extremity peripheral nerve injuries in the combat-related limb salvage population.

**Methods** We performed a retrospective review of all patients who underwent limb salvage procedures to include flap coverage for combat-related upper extremity trauma at a single institution between January 2011 and January 2020. We collected data on patient demographics; perioperative complications; location of nerve injuries; surgical interventions; chronic pain; and subjective, patient-reported functional limitations.

**Results** A total of 45 patients underwent flap procedures on 49 upper extremities following combat-related trauma. All patients were male with a median age of 27 years, and 96% (n = 47) of injuries were sustained from a blast mechanism. Thirty-three of the 49 extremities (67%) sustained associated nerve injuries. The most commonly injured nerve was the ulnar (51%), followed by median (30%) and radial/posterior interosseous (19%). Of the 33 extremities with nerve injuries, 18 (55%) underwent surgical intervention. Nerve repair/reconstruction was the most common procedure (67%), followed by targeted muscle reinnervation (TMR, 17%). Chronic pain and functional limitation were common following nerve injury.

**Conclusions** Upper extremity peripheral nerve injury is common following high-energy combat-related trauma with high rates of chronic pain and functional limitations. Surgeons performing limb salvage procedures to include flap coverage should anticipate associated peripheral nerve injuries and be prepared to repair or reconstruct the injured nerves, when feasible. *(J Hand Surg Am. 2023;■(■):1.e1-e5. Copyright © 2023 by the American Society for Surgery of the Hand. All rights reserved.)*

**Type of study/level of evidence** Therapeutic IV.

**Key words** Blast injuries, Flap reconstruction, Limb salvage, Peripheral nerve, War trauma.

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THE USE OF IMPROVISED EXPLOSIVE devices (IED) and other explosive munitions in modern warfare result in high-energy extremity trauma characterized by severe skeletal and soft tissue injuries.[1,2] As the advancement of body armor and expedited medical evacuation to far forward medical assets have increased survivability of these injuries, more patients are being treated for traumatic extremity injuries, reported in 54%−70% of blast-related injuries.[1,3] Peripheral nerve injuries are also common following blast trauma and can be overlooked or missed during the expedited medical evacuation process where multiple hand-offs, grossly contaminated wounds, and multiple distracting injuries can divert attention away from specific nerve injuries and delay initial diagnosis.[4] This is particularly relevant in the most severe cases of extremity trauma where the decision between limb salvage and amputation is often driven by infection and bone-healing concerns, with the impact of concomitant nerve injury often considered secondarily. Previously, combat-related peripheral nerve injuries have been reported at rates less than 10% in the setting of extremity trauma.[2,3] A review of combat-related peripheral nerve injuries from 2005 to 2010 among United Kingdom service personnel reported an incidence of 8.1%; however, this review excluded both traumatic amputations as well as sensory nerve injuries, underestimating the true prevalence of these injuries.[3]

We have treated a subset of combat-injured patients with chronic, neuropathic pain and persistent limb dysfunction following "successful" limb salvage, previously defined by an intact, perfused extremity.[5] Specific to lower extremity limb salvage, we found these patients are at risk for late amputation due to persistent complications, such as fracture nonunion and ongoing limb dysfunction.[5] While rates of conversion to amputation in combat-injured patients with severe upper extremities injuries necessitating flap coverage have been substantially lowered, chronic pain and loss of function secondary to upper extremity peripheral nerve injury remains a major barrier to achieving satisfactory function and quality of life, challenging the historical definition of success as an intact, perfused extremity at initial discharge.[5,6] Additionally, combat-related blast injuries are often accompanied by wound contamination and more severe soft tissue injuries and are at higher risk for complications, including amputation compared to typical civilian mechanisms of injury.[5,7] Previous literature has characterized combat-related peripheral nerve injuries during an earlier time when dismounted blast injuries were not as commonplace.[1,4,8] However, dismounted patrols in environments not accessible to traditional armored vehicles subject combatants to more direct blast exposures, resulting in higher rates of polytrauma and multi-extremity injuries as well as increasing rates of concomitant peripheral nerve injuries.[8] With this in mind, we sought to define the incidence and locations of upper extremity peripheral nerve injuries as well as pain and functional outcomes in a more recent subset of patients who underwent limb salvage with flap coverage for injuries sustained in combat.

## MATERIALS AND METHODS

After approval by our institutional review board, we performed a retrospective review of all patients who underwent limb salvage with flap coverage for combat-related upper extremity trauma in the United States Military Health System's National Capital Region between January 1, 2011, and January 31, 2020. We collected data on patient demographics; mechanism of injury; perioperative complications, incidence, and location of nerve injuries; type of peripheral nerve surgery performed; postoperative chronic pain; and subjective, patient-reported functional limitations following injury. Portions of this data set have been previously published regarding orthoplastic collaboration and flap outcomes.[9]

## RESULTS

We identified 45 patients (49 upper extremities) who were treated with limb salvage and flap coverage. Of the 49 flaps, 78% (n = 38) were free flaps, and 22% (n = 11) were pedicled flaps. All patients were male with a median age of 27 years [interquartile range (IQR): 22−30], and 96% (n = 47) of injuries were sustained from a blast mechanism (Table 1). At a median follow-up of 4.8 years (IQR: 2-1−6.6 years), 48 (98%) of the 49 extremities were successfully salvaged. One patient underwent a transradial amputation 3 years following initial injury owing to both chronic pain and poor function.

Of the 49 extremities treated with limb salvage and flap coverage, 33 (67%) had associated nerve injuries with a total of 47 injured nerves. The most commonly injured nerve was the ulnar nerve (n = 24, 51%), followed by the median nerve (n = 14, 30%) and the radial/posterior interosseous nerve (n = 9, 19%). Of the 14 extremities with multiple nerves injured, the median and ulnar nerves were most often injured together (n = 10, 71%), followed by the median and radial nerves (n = 2, 14%) and the ulnar and radial

**TABLE 1. Patient Demographics and Injury Characteristics (45 Patients, 49 Upper Extremities)***

| | |
|---|---|
| Age (years) | 27 (22−30) |
| Male | 45 (100) |
| Female | 0 |
| MOI | |
| ■ GSW | 2 (4) |
| ■ Explosive (RPG, grenade, mortar, landmine, IED) | 47 (96) |
| Nerve injury (n = 47) | |
| ■ Ulnar | 24 (51) |
| ■ Median | 14 (30) |
| ■ Radial/PIN | 9 (19) |
| Surgical interventions (n=18) | |
| ■ Nerve repair/reconstruction | 12 (67) |
| ■ TMR | 3 (17) |
| ■ Nerve transfer | 1 (6) |
| ■ Neurolysis | 1 (6) |
| ■ Nerve transposition | 1 (6) |

IED, improvised explosive device; GSW, gunshot wound; MOI, mechanism of injury; PIN, posterior interosseous nerve; RPG, rocket-propelled grenade; TMR, targeted muscle reinnervation.
*Data presented as median (IQR) or (n) %.

nerves (n=2, 14%). Of the 33 extremities with nerve injuries, 18 (55%) underwent surgery to address the nerve injury at a median of 26 days (IQR: 14−69 days). Nerve repair/reconstruction was the most common procedure (n = 12, 67%), followed by targeted muscle reinnervation (TMR, n = 3, 17%), nerve transfer (n = 1, 6%), neurolysis (n = 1, 6%), and nerve transposition (n = 1, 6%). Chronic pain and functional limitations were more common in the sample of patients with concomitant nerve injuries compared with those without and were reported in 45% versus 6% and 82% versus 43%, respectively (Table 2). The median numerical rating scale (NRS) pain score in patients with nerve injuries without operative intervention was 2 (IQR: 2−5) compared to a median score of 0 (IQR: 0−1) in patients who underwent operative management of the injured nerve.

## DISCUSSION

Upper extremity peripheral nerve injuries were common in this combat-related, limb salvage cohort, occurring in 67% of patients, which is more than five times higher than rates previously reported.[2,3] This finding is likely due to the extent of these high-energy, limb-threatening injuries with massive soft tissue loss and an extensive zone of injury necessitating flap reconstruction. In comparison, peripheral nerve injuries occur in 2.8% of civilian polytrauma patients annually among regional trauma facilities in North America.[10−12] In our cohort, multiple nerve injuries were relatively common, and the ulnar nerve was the most frequently affected. Chronic pain and patient-reported functional limitations were more common among patients with concomitant peripheral nerve injuries, and operatively managed nerve injuries demonstrated decreased pain scores compared to nonsurgically injured nerves.

The frequency of blast injuries and subsequent rate of combat-related peripheral nerve injuries have both increased in recent years. For example, Owens et al[2] reported a 4% incidence of peripheral nerve injury among 3575 combat extremity wounds from 2001 to 2005. The most common mechanism of injury was an IED blast, accounting for 36% of all injuries.[2] As dismounted complex blast injuries have become increasingly common, we have treated an increasing number of polytraumatized patients with severe extremity trauma.[8] In a retrospective review of combat-sustained peripheral nerve injuries from 2004 to 2009, Eckhoff et al[1] detailed 104 patients with 144 lower extremity nerve injuries, a majority (56.6%) of which were due to an IED blast. The results of our study further demonstrate the increasing trend of nerve injuries secondary to a blast mechanism as greater than 95% of patients in our cohort sustained their injuries from an IED.

The three most injured nerves in our cohort were the ulnar, median, and radial nerves, similar to those reported in previous studies with isolated (eg, non-radial) posterior interosseous nerve injuries being rare and no cases of musculocutaneous nerve injury in our cohort.[1,3,4] For instance, among 261 combat-sustained peripheral nerve injuries in United Kingdom service members, the ulnar and median nerves were the most commonly injured in the upper extremity, accounting for 13% and 11% of injuries, respectively.[3,13] Similarly, Dunn et al[4] highlighted the incidence of nerve injuries presenting to a multidisciplinary, peripheral nerve clinic among United States' service members injured in combat. Of the 138 nerve injuries, the ulnar nerve (35%) and median nerve (24%) were the most affected.[4]

Outcomes following surgical management of combat-related peripheral nerve injuries have been inconsistent and associated with several factors, such as time to presentation, operative intervention, and the level and severity of initial injury.[1,4,13] Chronic

**TABLE 2. Pain and Functional Limitations Following Limb Salvage with Flap Coverage**

| All Upper Extremities Treated With Limb Salvage and Flap Coverage | Chronic Pain | Functional Limitations | NRS Pain Scores |
|---|---|---|---|
| Extremities with associated nerve injuries (n = 33) | 15 (45) | 27 (82) | 1.5 (0−4.3) |
| Nerve injuries with surgical intervention (18 patients, 18 procedures) | 6 (33) | 14 (78) | 0 (0−1) |
| Nerve injuries without surgical intervention (n = 15 patients) | 9 (60) | 13 (87) | 2.3 (2−5) |
| Extremities without associated nerve injuries (n = 16) | 1 (6) | 7 (43) | 0 (0−0) |

Data presented as median (IQR) or (n) %.
IQR, interquartile range; NRS, numerical rating scale.

neuropathic pain and subjective, functional limitations are common outcomes of these injuries, and these conditions developed in a majority of patients in our cohort. Birch et al[13] reported similar findings where persistent neuropathic pain was the primary driver for late reoperation following combat-related peripheral nerve injuries. Of the 36 patients requiring revision operation secondary to neuropathic pain in that study, 30 (83%) patients reduced or discontinued analgesic medication following the revision procedure. Similarly, the operative intervention in our cohort demonstrated decreased NRS pain scores compared to injured nerves treated nonsurgically. In contrast to combat-sustained peripheral nerve injuries, outcomes following peripheral nerve injuries in the civilian trauma setting have demonstrated more favorable outcomes.[12] For example, Noble et al[12] reported "good" or "normal" functional outcomes in 56% of patients following 200 peripheral nerve injuries treated at a regional Level 1 trauma center with 22% of patients reporting poor recovery following injury. These outcomes are in contrast to the results of the current study as well as previous studies in a combat-injured population, citing much higher rates of functional disability and chronic pain at upwards of 80% and 30%, respectively.[14] While further analysis of pain-related outcomes stratified by specific surgical intervention may highlight differences between procedures, most of our patients underwent nerve repair/reconstruction or TMR, limiting comparison to less frequently performed procedures, such as nerve transfer and nerve transposition. As outlined by previous authors, prompt surgical repair/reconstruction when feasible, TMR in the setting of unreconstructable nerve injuries and chronic neuroma-related pain, physical and occupational therapy, and adjunctive pharmacologic agents have helped prevent and relieve symptoms in our subset of patients.[15]

In contrast to previous studies where time from injury to initial evaluation was on the order of several months, we identified all nerve injuries shortly after the time of injury or after evacuation from the combat zone, which may be attributed to the development of a multidisciplinary peripheral nerve program focused on prompt evaluation and management of peripheral nerve injuries within the military health care system.[1,3,4,16] Although there is a lack of consensus regarding optimal timing to repair of peripheral nerve injuries, earlier diagnosis and surgical management has demonstrated improved outcomes in numerous studies.[1,13,17,18] However, even with early diagnosis and timely intervention, chronic pain was common in our cohort of patients, which may be partially attributed to the severity of initial injury as well as the setting in which the injury occurred. Throughout the study period, operative intervention for peripheral nerve injuries increased, likely due to the increased availability of surgeons interested and equipped to manage these complex injuries as well as the increased utilization of TMR and other novel, nerve reconstruction techniques that were in their infancy in the early study period.[19,20]

This study is limited by its retrospective nature and subject to the inherent biases associated with such reviews. Other major limitations of our study were the lack of characterization of both motor and sensory outcomes following peripheral nerve injuries as well as insufficient statistical power to allow additional comparisons between groups, type of operative intervention, and functional outcomes, which poses several issues. Our lack of characterization of postinjury motor and sensory nerve function makes it difficult to delineate the severity of initial injuries, introducing selection bias as operatively treated nerve injuries were likely more severe and predisposed to worse outcomes. Furthermore, classification of functional limitations was based on self-reported dysfunction as documented in the electronic medical record and not standardized using patient-reported outcome measures, decreasing the level of granularity in characterizing these injuries. Improvement in nerve function is difficult to quantify without objective postoperative motor and sensory function assessments or subjective patient-reported outcomes. Additionally, we did not identify any concomitant or isolated superficial sensory nerve injuries within this retrospective review, which may be attributed to an emphasis on documentation of pure motor or mixed motor and sensory nerves that typically present with more profound functional deficits. Finally, numerous other factors, such as associated fractures, tendon, soft tissue, vascular, and articular injuries, also contribute to long-term functional limitations. These associated injuries were not factored into assessing functional limitations for each patient as they were classified by subjective, self-reported function during routine follow-up, thus limiting the strength of association between nerve injury and subjective functional limitations. While the purpose of this study was to highlight the prevalence, distribution, and pain-related sequelae of peripheral nerve injuries in this population, we recognize the lack of objective outcomes limits the conclusions and recommendations from the data.

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