SCIENTIFIC ARTICLE

Gunshot-Related Upper Extremity Nerve Injuries at a Level 1 Trauma Center

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Purpose Gunshot wounds can result in a spectrum of injuries to nerves, with little data to guide definitive treatment. We performed a retrospective evaluation of gunshot-related upper extremity injuries in an urban trauma center to analyze epidemiology, associated injuries, and short-term outcomes. We hypothesized that gunshot-related injuries would involve soft tissue cavitation, inducing axonotmesis and neuropraxia rather than neurotmesis injuries.

Methods All patients over the age of 16 with upper extremity gunshot trauma from May 2018 to May 2019 were identified through the University of Chicago orthopaedic and general surgery trauma databases. Initial nerve injuries were identified by physical examination. Patient demographic data, soft tissue and skeletal injury, treatment modality, and return of function were collected.

Results Ballistic injuries in 1302 patients were treated over 12 months. We identified 126 upper extremity gunshot injuries in 117 patients. Thirty-eight upper extremities (38 patients) had a documented nerve deficit (38/126, 30%) with a follow-up rate of 94% (34/36) at a mean of 351 days after injury (median, 202 days; range, 13-929 days). One patient had a subacute transradial amputation, and 1 patient was deceased at final follow-up. The presence of vascular injury and fracture increased the rate of neurologic injury after gunshot injuries. At the most recent follow-up, 68% (23/34) of patients with upper extremity injury had improvement in nerve function as measured by objective clinical assessment, with 24% (8/34) experiencing full recovery at an average of 368 days (median, 261 days; range, 41−929 days).

Conclusions Nerve injury after ballistic trauma to the upper extremity is common. Vascular injury and fractures were associated with a higher risk of nerve injury. Short-term improvement in nerve function was seen in over half the cohort, suggesting a predominance of neuropraxic effects. *(J Hand Surg Am. 2022;47(1):88.e1-e6. Copyright © 2022 by the American Society for Surgery of the Hand. All rights reserved.)*

Type of Study/Level of Evidence Prognostic IV.

Key words Ballistic, epidemiology, nerve, outcomes, vascular.

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Civilian ballistic trauma is a public health issue with a disproportionate impact on both patients and resource usage in urban medical centers. The homicide rate because of gun violence in the United States is nearly 10 times higher than that of most European countries.[1] Historically, most data on the impact of ballistic injuries have originated from military conflicts. In contrast to military injuries, gunshot injuries in the urban setting cause low-energy penetrating trauma. Aside from the direct

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trauma caused by the primary and secondary ballistic missiles, both high- and low-velocity ballistic injuries impart a shockwave and cavitation that may lead to extensive soft tissue stretching, compression, and shearing.[2] The neurologic impact of cavitation results in a spectrum of nerve injury from neuropraxic stretch to frank nerve laceration.[3] While full recovery can occur, nerve injuries can result in permanent sensory or motor loss, chronic pain, and disability.

Most of the data on nerve injury associated with ballistic trauma is derived from analysis of national registry data or single-institution retrospective cohort studies; with cohorts assembled over multiple years.[4–11] Our catchment area experiences a high yearly rate of ballistic trauma. The University of Chicago general surgery trauma database captures all trauma patients, including gunshot injuries, and we also capture specific musculoskeletal-related injuries in our orthopaedic trauma database. Therefore, gunshot injuries are tracked in both databases at our trauma center. In this retrospective cohort study, we aimed to describe the frequency of nerve injury associated with upper extremity ballistic trauma, the associated skeletal and soft tissue injuries, and the rate of neurologic recovery. We hypothesized that injuries in the ballistic population induce soft tissue cavitation, causing axonotmesis and neuropraxia rather than neurotmesis type injuries.

MATERIALS AND METHODS

The University of Chicago institutional review board approved study of patients over 16 years of age presenting with gunshot-related traumatic injury to the upper extremities at our level 1 trauma center. Between May 2018 and May 2019, 1,302 patients presented to our institution as trauma level activations. All patients identified as having upper extremity ballistic trauma were included in this study. Reviews of the University of Chicago orthopaedic and general surgery trauma databases were performed with auditing of charts to ensure adequate capture of any patient with possible neurologic injury. Patients who sustained 1 or more ballistic injuries to the upper extremity with fascial penetration, for which orthopedic surgery was consulted, were included in the study and coded as either single or multiple injuries to a given extremity. Exclusion criteria were patients with concomitant spinal cord injury, pre-existing neurologic dysfunction, brachial plexus injuries, isolated lower extremity ballistic injury, and age less than 16 years. The cohort obtained within our departmental database was then cross-referenced with the general surgery trauma database to ensure adequate capture.

Initial nerve injury was evaluated with the assessment of sensation and strength, using a 0−2 grade (modified American Spinal Injury Association scale) and Medical Research Council (MRC) muscle power scale respectively.[12] For sensation, 0 designates no sensation, 1 represents incomplete loss of sensation, and 2 is assigned to patients with no subjective sensory deficit. The MRC scale uses a 0−5 designation to grade muscle power in relation to the maximum expected for that muscle.[12] The overall frequency of nerve dysfunction in the upper extremities was calculated.

Upper extremities were further analyzed by the segment of the limb in which the gunshot trauma occurred. When a single patient received multiple gunshots to a single extremity, we examined the location of the injuries and the nerve distribution affected. Anatomic regions were used for ease of describing the cutaneous location of these wounds and divided into arm (from medial scapular border to the antecubital fossa), forearm (antecubital fossa to the wrist crease), and hand (distal to the wrist crease). We did not include ballistic brachial plexus nerve injuries because other clinical services are typically consulted for these injuries, and this was outside the scope of this study. For each anatomic region, the frequency of associated skeletal injury, rate of operative fixation, and nerve palsy rate were recorded. Nerves included in the upper extremity analysis included the radial, ulnar, median, posterior interosseous nerve, anterior interosseous nerve, musculocutaneous, axillary, and cutaneous sensory nerves. In cases where a nerve at risk could not be localized by the general location of the wound, we assumed the most proximal injury was the cause of the nerve injury. For example, a patient with multiple injuries, including a gunshot with ballistic mid-shaft humerus fracture and a carpal ballistic injury, with an associated high radial nerve injury, would be categorized as having a radial nerve injury caused by the proximal nerve injury based on anatomic considerations.

Rates of associated fracture, compartment syndrome, and concomitant vascular injury were collected through a review of operative reports. A clinical chart review was performed to evaluate outcomes and nerve recovery. Descriptive statistics were used to evaluate patient and injury characteristics as well as follow-up.

RESULTS

Our trauma center treated ballistic injuries in 1,302 patients over a 12-month period. Of these, 650

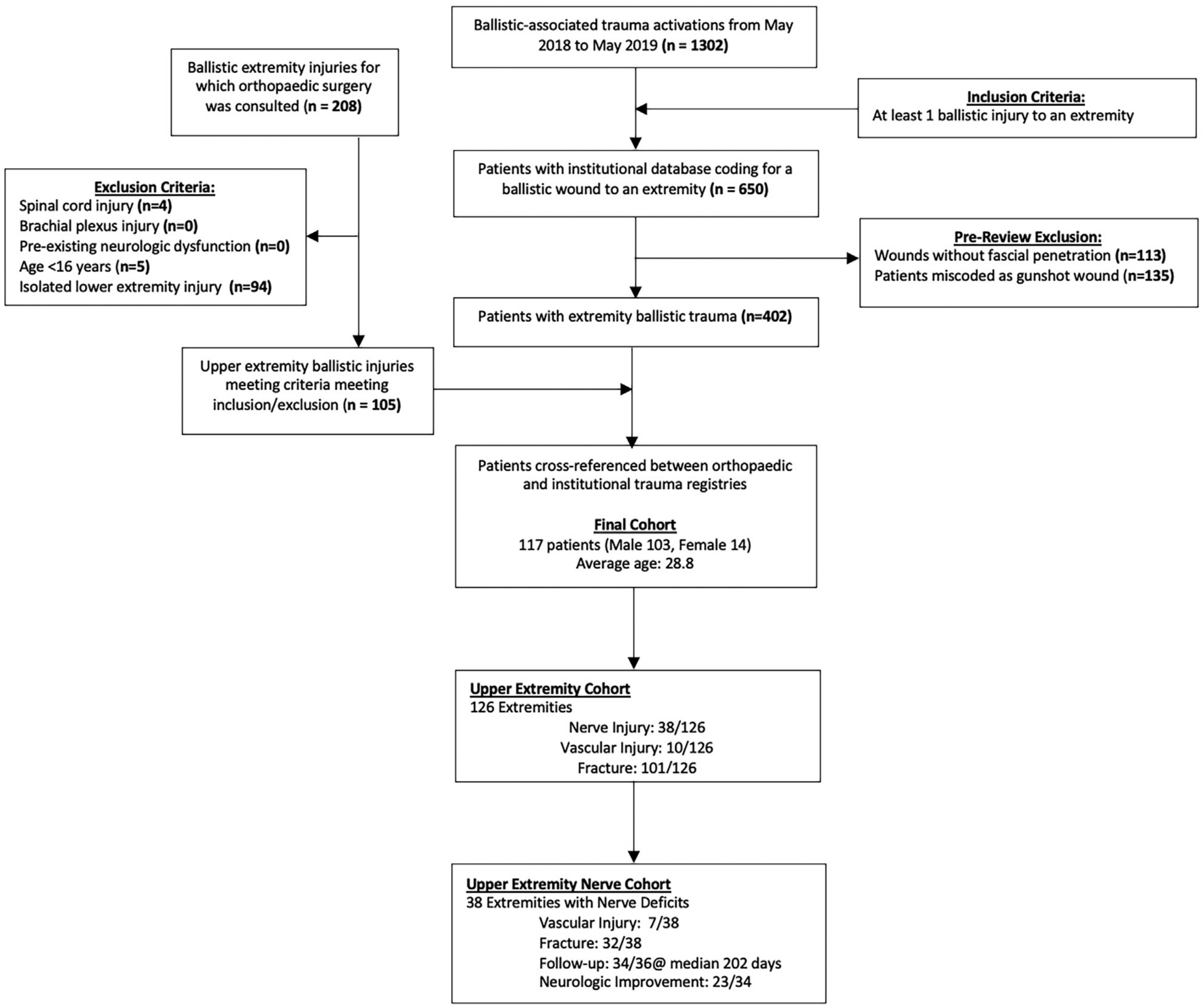

FIGURE 1: Flow chart demonstrating the inclusion/exclusion criteria for the cohort, as well as injury characteristics.

patients were coded with extremity gunshot wounds in an audit of our general surgery trauma database. Upon detailed chart review, 113 patients had superficial gunshot wounds that did not breach the fascia and were excluded. Of all ballistic trauma activations, an additional 135 patients (10%) were initially coded as extremity gunshot injuries by the trauma research staff, in most cases because of abrasions, grazing injuries, soft tissue and bony injuries, that were later attributed to unrelated mechanisms, such as a fall, impact, or etiology other than a gunshot injury (ie, a both bones forearm fracture in a patient who suffered an isolated gunshot to the chest, who then injured their arm in a motor vehicle crash). Of the remaining patients (402), 117 (126 extremities) were identified as having ballistic injuries (bone, tendon, joint, or nerve related) to the upper extremity and were treated either in the emergency room, inpatient, or outpatient settings. Thirty-eight patients (38 extremities, 30%) were diagnosed by attending physicians, fellowship-trained in hand or orthopedic trauma, as having gunshot-related nerve injury. One patient was deceased at final follow-up and had experienced no return of function by 3 months, and 1 patient underwent transradial amputation for complications following a vascular injury. Two patients were lost to follow-up after surgery despite multiple attempts to contact them. Clinical follow-up was therefore available for 34/36 (94%) at a mean of 351 days (median, 202 days; range, 13−929 days) after injury (Figure 1).

Overall, 30% (38/126) of upper extremity gunshot wounds resulted in a recorded peripheral nerve injury (Table 1). When stratified by ballistic wound location, the radial nerve and/or posterior interosseous nerve were the most commonly affected with a total of 21/38 (55%) (Table 1). Nerve exploration was performed during fracture management in 19 patients

TABLE 1. Upper Extremity Nerve Injury by Ballistic Wound Location*

Location of GSW(s)	Arm	Forearm	Arm + Forearm	Hand	Total
Extremity, n	18	13	6	1	38
Nerve Injury by GSW location					
Axillary	3	0	0	0	3
Median/AIN	5	2	2	0	9
Musculocutaneous	1	0	0	0	1
Radial/PIN	11	5	5	0	21
Ulnar	4	9	2	1	16
Cutaneous nerves	1	0	0	0	1
Nerve recovery, n	9/15†	9/13†	5/5†	0/1	23/34†
Associated fracture, n	15/18	11/13	5/6	1	32/38
Compartment syndrome, n	1/18	1/13	0	0	2/38
Vascular injury, n	4/18	1/13	1/6	1	7/38

AIN, anterior interosseous nerve; GSW, gunshot wound; PIN, posterior interosseous nerve.

*"Location" designates the location of presumed ballistic penetration site: "Arm" extends from medial scapular border to the antecubital fossa, "Forearm" extends distal from antecubital fossa to the wrist crease, and "Hand" encompasses extremity distal to the wrist crease. Within each anatomic location, the frequency of nerve injury is provided. Note: the total amount of involved nerves in each column may sum to greater that the total number of extremities in each anatomic location. This is because of several limbs with multiple-nerve involvement.

†Nerve recovery (for the 34 patients with follow up at a median 202 days), associated fracture, compartment syndrome, and vascular injury are also noted.

with 1 patient explored in a delayed fashion. Neurotmesis was identified in 4 patients (21%, 4/19); the remaining nerves were intact at exploration (79%, 15/19), with variable degrees of contusion. Vascular injury, defined as vessel injury requiring either surgical or interventional radiology treatment, occurred in 18% (7/38), of upper extremities with nerve palsy and 3% of upper extremities without nerve palsy (3/88). The overall rate of vascular injury for the upper extremity cohort was 8% (10/126). Fracture was present in 80% of upper extremities (101/126); when ballistic nerve injury was present, fracture was observed in 84% of cases (32/38).

At the most recent follow-up, 68% (23/34) of nerve injury patients available for follow-up had interval improvement in sensory and/or motor function. Eight patients (24%, 8/34) demonstrated complete nerve recovery as measured by the MRC scale at 367 days following injury, while the rest displayed residual deficits. Thus, 32% (11/34) had not recovered at mean 2.5 months follow-up (median, 59 days; range, 13−173 days) and 44% (15/34) had only partial recovery at a mean follow-up of 546 days (median, 712 days; range, 19−864 days).

DISCUSSION

Gunshot wounds to the extremities can lead to permanent neurovascular injury, chronic pain, and disability.[7,13−17] The mechanism of nerve injury from ballistic missiles has been described as both a direct impact from the projectile traveling through tissue, as well as the shock wave and cavitation that expands the zone of injury, but reports of the frequency of nerve palsy are highly variable.[14,18-21] Nerve injuries after gunshot wounds have been previously reported; a large national trauma database study reported nearly 7,000 patients who had sustained isolated extremity ballistic trauma. Vascular and neurologic injuries from this study were recorded as 6% and 3.6%, respectively.[6] However, more granular data is difficult to glean from registry studies of this kind because there is little information regarding patient characteristics and outcomes.

Our cohort provides the unique opportunity to characterize nerve injuries and outcomes in a large sample of civilian gunshot trauma.[22,23] Nerve injury after upper extremity ballistic trauma in this group occurred in 30%, comparable to other series (15−50%).[11,18,19,21] The most common nerve injury was the radial nerve (including superficial radial and posterior interosseous branches) with 21 of 38 patients demonstrating decreased nerve function (55%), followed by the ulnar nerve in 16 of 38 patients (42%). Similar to our findings, Pannell et al[21] noted the highest frequency of nerve palsy in the radial nerve distribution at 40.5%, followed by the ulnar nerve at 35.1%. In contrast, a retrospective review of 1,565 patients presenting over a 10-year period with upper and lower extremity peripheral nerve injury (approximately 56.3% due to gunshot wounds) demonstrated the highest rate of nerve palsies in the median (32.3%) and ulnar nerve (24.1%).[24] Their reported rate of radial nerve injury was 12.1%, which could be attributed to the inclusion of other traumatic mechanisms, such as knife or explosive trauma.[24]

The spectrum of sequelae from gunshot injuries goes beyond the peripheral nerve impact. We examined associated skeletal and vascular trauma in our patients and noted fracture in 84% of extremities with nerve injury (32/38). This rate is higher than that reported by several other single-center cohort or large database reviews, ranging from 22 to 48%.[4–6] Pannell et al[21] did not find upper extremity fracture to be predictive of nerve injury, yet a large database review by Berg et al[6] demonstrated that upper extremity fracture was associated with an odds ratio of 2.6 for nerve palsy. A retrospective review by Mehta[11] similarly found proximal-third forearm fractures to be predictive of neurologic injury with an odds ratio of 5.7.

On evaluation of the relationship between ballistic vascular injury and nerve palsy, we noted concomitant vascular injury in 18% (7/38) of our cohort. Similarly, Sitzmann et al[26] demonstrated 54% upper extremity nerve dysfunction with traumatic vascular injury, while another study noted a 28% incidence of vascular injury when peripheral nerve injury was documented on the examination and intraoperative evaluations.[11,25]

With a short-term follow-up of 34/36 patients at a mean of 351 days (median, 202 days), we noted 23/34 (68%) upper extremity nerve injuries with a documented improvement of function. However, only 8/34 (24%) subjects exhibited complete resolution of nerve palsy with 1 year of mean follow-up in this cohort, and partial improvement was observed in 44% (15/34) with a mean follow-up of 546 days (median, 712 days). The remaining patients demonstrated no neurologic recovery (32%, 11/34); however, their follow-up was the shortest (mean, 2.5 months; median, 59 days) and thus we may not have captured further nerve recovery. Even considering the short-term follow-up, these findings are unexpected given previous literature noting that most ballistic nerve injuries are neuropraxic in nature.

Although no definitive conclusions can be made given the inconsistent follow-up, one explanation could be an underestimation of the number of more permanent nerve injuries, as opposed to temporary stretch injuries. At surgical exploration in 19 patients, nerve lacerations were identified in 4 patients (21%) with the remaining patients noted to have contused, but intact nerves. With one-fifth of explored nerve injuries demonstrated to be neurotmetic, this would suggest a lower rate of ultimate recovery and coincides with the 32% of patients who demonstrated no neurologic recovery. Over half of the current cohort demonstrated signs of nerve recovery in the short term, suggesting that many of these injuries are neuropraxic injuries.

The major limitation of this study is the short length of follow-up, which may have skewed the results to suggest that permanent nerve injury is a common outcome after a gunshot wound. Our recovery rate for upper extremity ballistic nerve palsy was lower than reported by Omer,[14] who conducted a military-based series evaluating upper extremity peripheral nerve injuries. Of 917 injured extremities followed over a 56-month period, spontaneous nerve recovery was noted in 70% of gunshot wounds. This review also provided time frames for expected nerve recovery for above-elbow and below-elbow ballistic injuries, which were 4 to 8 months and 3 to 7 months, respectively.[14] Even those in favor of early exploration advocated waiting for repair or grafting until 3 to 4 months after injury.[7,27–30] Our mean follow-up of 2.5 months (median, 59 days) for patients who had not recovered may represent a series of patients with recovery trajectories that have yet to declare themselves. That being said, nearly half (17/36) of our nerve injury cohort were followed for over 6 months. Within this subgroup, all patients exhibited some degree of nerve recovery (6 complete and 11 partial). This would suggest that further follow-up may be required before seeing spontaneous recovery by the remainder of our patients with nerve injury.

Other limitations include the single-center retrospective analysis and the potential lack of complete capture of all upper extremity injuries. While 2 trauma databases were evaluated and audited, chart review within a retrospective database is fraught with potential recall and missing data bias. However, by independently evaluating both the orthopaedic and general surgery databases and reviewing our electronic medical records, we have minimized this potential source of bias as much as possible. As with any clinical evaluation of patients, the definition and appropriate categorization of outcomes can be difficult. Defining nerve injury based on physical examination is a subjective measure, particularly when completed by different providers; electromyography is more objective but is not generally conducted in the acute setting.[31] We used manual motor testing, which has been shown to be a viable modality for the evaluation of peripheral nerve lesions of the upper extremity, with substantial inter- and intra-observer reliability.[32,33] The reproducibility of these exam maneuvers allows for routine monitoring of the recovering patient with nerve palsy. Optimal expanded nerve functional testing would include Semmes-Weinstein testing, two-point discrimination, and if persistent palsy is present, early electromyography.[27,31]

Ultimately, in this analysis of nerve injury after gunshot wounds in a civilian urban population, we noted a high rate of concomitant vascular and bone injuries. At a short-term follow-up of 6 months, just over two-thirds of the cohort showed some signs of nerve recovery. Surgical exploration of a subset of these injuries indicated that 21% sustained nerve lacerations, portending poorer outcomes. Further study is needed to improve surgical decision-making and patient counseling in this challenging injury.

REFERENCES

1. Global Burden of Disease 2016 Injury CollaboratorsNaghavi M, Marczak LB, et al. Global Mortality From Firearms, 1990-2016. *JAMA*. 2018;320(8):792−814.
2. Dicpinigaitis PA, Koval KJ, Tejwani NC, Egol KA. Gunshot wounds to the extremities. *Bull NYU Hosp Jt Dis*. 2006;64(3-4):139−155.
3. Bartlett CS, Helfet DL, Hausman MR, Strauss E. Ballistics and gunshot wounds: effects on musculoskeletal tissues. *J Am Acad Orthop Surg*. 2000;8(1):21−36.
4. Abghari M, Monroy A, Schubl S, Davidovitch R, Egol K. Outcomes following low-energy civilian gunshot wound trauma to the lower extremities: results of a standard protocol at an urban trauma center. *Iowa Orthop J*. 2015;35:65−69.
5. Backman PB, Riddez L, Adamsson L, Wahlgren CM. Epidemiology of firearm injuries in a Scandinavian trauma center. *Eur J Trauma Emerg Surg*. 2020;46(3):641−647.
6. Berg R, Okoye O, Inaba K, et al. Extremity firearm trauma: the impact of injury pattern on clinical outcomes. *Am Surg*. 2012;78(12): 1383−1387.
7. Secer HI, Daneyemez M, Tehli O, Gonul E, Izci Y. The clinical, electrophysiologic, and surgical characteristics of peripheral nerve injuries caused by gunshot wounds in adults: a 40-year experience. *Surg Neurol*. 2008;69(2):143−152; discussion 152.
8. Byrne A, Curran P. Necessity breeds invention: a study of outpatient management of low velocity gunshot wounds. *Emerg Med J*. 2006;23(5):376−378.
9. Burg A, Nachum G, Salai M, et al. Treating civilian gunshot wounds to the extremities in a level 1 trauma center: our experience and recommendations. *Isr Med Assoc J*. 2009;11(9):546−551.
10. Pereira CT, Boyd JB. Outcomes of complex gunshot wounds to the hand and wrist: a 10-year level I urban trauma center experience: reply. *Ann Plast Surg*. 2013;71(1):126.
11. Mehta SK, Dale WW, Dedwylder MD, Bergin PF, Spitler CA. Rates of neurovascular injury, compartment syndrome, and early infection in operatively treated civilian ballistic forearm fractures. *Injury*. 2018;49(12):2244−2247.
12. Compston A. Aids to the investigation of peripheral nerve injuries. Medical Research Council: Nerve Injuries Research Committee. His Majesty's Stationery Office: 1942; pp. 48 (iii) and 74 figures and 7 diagrams; with aids to the examination of the peripheral nervous system. By Michael O'Brien for the Guarantors of Brain. Saunders Elsevier: 2010; pp. [8] 64 and 94 Figures. *Brain*. 2010;133(10): 2838−2844.
13. Griggs RB, Bardo MT, Taylor BK. Gabapentin alleviates affective pain after traumatic nerve injury. *Neuroreport*. 2015;26(9):522−527.
14. Omer GE Jr. Injuries to nerves of the upper extremity. *J Bone Joint Surg Am*. 1974;56(8):1615−1624.
15. Davis G, Curtin CM. Management of pain in complex nerve injuries. *Hand Clin*. 2016;32(2):257−262.
16. Wood P, Small C, Lewis S, Mahoney P. Neuropathic pain treatment and research: experiences from the United Kingdom mission to Afghanistan and future prospects. *J R Army Med Corps*. 2018;164(3): 207−212.
17. Xu J, Murphy SL, Kochanek KD, Bastian B, Arias E. Deaths: final data for 2016. *Natl Vital Stat Rep*. 2018;67(5):1−76.
18. Kouyoumdjian JA. Peripheral nerve injuries: a retrospective survey of 456 cases. *Muscle Nerve*. 2006;34(6):785−788.
19. Kouyoumdjian JA, Graca CR, Ferreira VFM. Peripheral nerve injuries: a retrospective survey of 1124 cases. *Neurol India*. 2017;65(3):551−555.
20. Elstrom JA, Pankovich AM, Egwele R. Extra-articular low-velocity gunshot fractures of the radius and ulna. *J Bone Joint Surg Am*. 1978;60(3):335−341.
21. Pannell WC, Heckmann N, Alluri RK, Sivasundaram L, Stevanovic M, Ghiassi A. Predictors of nerve injury after gunshot wounds to the upper extremity. *Hand (N Y)*. 2017;12(5):501−506.
22. Aaland MO, Marose K, Zhu TH. The lost to trauma patient follow-up: a system or patient problem. *J Trauma Acute Care Surg*. 2012;73(6):1507−1511.
23. Zelle BA, Bhandari M, Sanchez A, Probst C, Pape HC. Loss of follow-up in orthopaedic trauma: is 80% follow-up still acceptable? *J Orthop Trauma*. 2013;27(3):177−181.
24. Daneyemez M, Solmaz I, Izci Y. Prognostic factors for the surgical management of peripheral nerve lesions. *Tohoku J Exp Med*. 2005;205(3):269−275.
25. Rodrigues RL, Sammer DM, Chung KC. Treatment of complex below-the-elbow gunshot wounds. *Ann Plast Surg*. 2006;56(2): 122−127.
26. Sitzmann JV, Ernst CB. Management of arm arterial injuries. *Surgery*. 1984;96(5):895−901.
27. Omid R, Stone MA, Zalavras CG, Marecek GS. Gunshot wounds to the upper extremity. *J Am Acad Orthop Surg*. 2019;27(7): e301−e310.
28. Akhavan-Sigari R, Mielke D, Farhadi A, Rohde V. Study of radial nerve injury caused by gunshot wounds and explosive injuries among Iraqi soldiers. *Open Access Maced J Med Sci*. 2018;6(9):1622−1626.
29. White J. Timing of nerve suture after a gunshot wound. *Surgery*. 1960;107(4):776−783.
30. Secer HI, Daneyemez M, Gonul E, Izci Y. Surgical repair of ulnar nerve lesions caused by gunshot and shrapnel: results in 407 lesions. *J Neurosurg*. 2007;107(4):776−783.
31. Berquist ER, Hammert WC. Timing and appropriate use of electrodiagnostic studies. *Hand Clin*. 2013;29(3):363−370.
32. Paternostro-Sluga T, Grim-Stieger M, Posch M, et al. Reliability and validity of the Medical Research Council (MRC) scale and a modified scale for testing muscle strength in patients with radial palsy. *J Rehabil Med*. 2008;40(8):665−671.
33. Brandsma JW, Schreuders TA, Birke JA, Piefer A, Oostendorp R. Manual muscle strength testing: intraobserver and interobserver reliabilities for the intrinsic muscles of the hand. *J Hand Ther*. 1995;8(3):185−190.