High Velocity Gunshot Fractures of Humerus: Results of Primary Plate Osteosynthesis

Manoj Kumar¹ · J. P. Khatri² · C. M. Singh³

Received: 27 August 2020 / Accepted: 21 October 2020 / Published online: 6 November 2020
© Indian Orthopaedics Association 2020

Abstract

Background High velocity gunshot fractures usually seen in conflict zones, often mandate external fixation due to delayed presentation and associated contamination. In the presented observational study, we managed high velocity gunshot fractures of humerus with adequate debridement and primary plate osteosynthesis under controlled conditions with gratifying results.

Material and Methods Eighteen consecutive cases of fracture of the humerus secondary to high velocity gunshot wounds with ages ranging from 28 to 45 years reporting within 6 h of the initial injury formed our study group. Immediate debridement, lavage and primary plate osteosynthesis was carried out following hemodynamic stabilisation and intravenous antibiotics. All the cases were followed up at 2, 4, 6 months, 1 year and then annual follow-up including telephonic follow-up for six patients.

Results Fifteen cases of Gustillo Anderson type III A, two of type III B and one of type III C were managed with primary plate osteosynthesis. Brachial artery injury was addressed immediately, however injured radial nerve ends were tagged. Five cases showed delayed/non-union and were managed with decortication and autologous bone grafting. Two cases of deep infection could be managed with implant retention till union. The implants were removed following fracture consolidation. All the fractures united and no patient was left with sequelae of chronic infection.

Conclusion Timely presentation of high velocity gunshot fractures of humerus teamed up with adequate debridement, soft tissue management and primary plate osteosynthesis can offer satisfactory outcomes. Associated vascular injury needs immediate attention. Nerve injuries can be addressed in a staged procedure. Our results have been satisfactory and add to the scant literature available on the subject, however further studies are warranted.

Keywords Gunshot · Humerus · Open fracture · Internal fixation

Introduction

High velocity gunshot wounds are generally seen in conflict zones common in military settings. The energy imparted to the bone and the surrounding soft tissue, compounded with

gross contamination, in the setting of delayed presentation often mandates stabilization with external fixation. Traditionally, caution has been advocated during internal fixation of such fractures due to a higher risk of infection [1].

We present an observational study of high velocity gunshot fractures of humerus which were managed with adequate debridement and primary plate osteosynthesis. The objective of the study was to analyse and compare the results of such management in terms of fracture union and infection rates in the light of limited available literature. The study tried to establish the role of primary internal fixation in the management of the said injuries as this could circumvent the need for multiple subsequent surgeries and shorten the treatment duration.

✉ J. P. Khatri
jaikhatri51@gmail.com

Manoj Kumar
nirvan009@gmail.com

C. M. Singh
cmsingh@gmail.com

¹ Department of Orthopaedics, 92 Base Hospital, Srinagar, Jammu and Kashmir 190004, India

² Department of Orthopaedics, Base Hospital Delhi Cantt, New Delhi 110010, India

³ Department of Orthopaedics, AFMC, Pune 411040, India

Material and Methods

An observational study of open fractures of the humerus was conducted at an orthopaedic referral centre located in an armed conflict zone from Jan 2016 to May 2018. All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008. Patients with high velocity gunshot injury of arm leading to fracture of the humerus who presented to our hospital within 6 h of sustaining the injury were included in the study. Patients with other limb injuries and/or systemic or visceral injuries which render them unsuitable for primary internal fixation were proposed to be excluded from the study. However, co-existing vascular or neurological injuries did not form an exclusion criterion.

Upon presentation to the emergency department, hemodynamic stability and neurovascular status of the limb was assessed. Fluid resuscitation, if indicated and intravenous antibiotics as per institutional protocol were administered. Orthogonal radiographs were obtained to assess and document the skeletal injuries. Informed written consent was obtained for immediate wound lavage, debridement, skeletal stabilization and soft tissue management. The decision to internally fix the fracture or restrict to external fixator stabilisation was made intraoperatively following adequate debridement.

Our antibiotic policy included injection cefoperazone (1000 mg) with sulbactam (1000 mg) 12 hourly, injection amikacin (750 mg) 24 hourly, and injection metronidazole (500 mg) intravenous 8 hourly. These antibiotics were administered for 72 h postoperatively to provide adequate coverage for gram positive, gram negative and anaerobic microorganisms.

Postoperative follow-up visits were scheduled at 2, 4, 6 and 12 months following surgery and annually thereafter. The outcome measures studied included fracture union and infection rates. Clinical and radiological evidence of fracture union and possibility of infection were noted at each visit. Fractures were considered to be united upon appearance of bridging callus in three cortices on two orthogonal views. Infections have been categorised as early superficial wound infection and chronic implant related infection or osteomyelitis. Six patients were not able to attend the clinic physically after 3 months and telephonic follow-up was maintained for them with clinical photos and photos of radiographs using Whatsapp™ messenger. All the data were extracted from case records and compiled in Microsoft excel sheet. Descriptive statistics were calculated to depict the results.

Results and Observations

Eighteen consecutive cases of fracture of the humerus secondary to high velocity gunshot wounds satisfying inclusion and exclusion criteria formed our study group. Majority of the bullets belonged to the Avtomat Kalashnikova (AK) family of automatic assault rifles which are high velocity weapons with muzzle velocity above 700 m/s. All the patients were male with a mean age of 36 years. Sixty six percent cases had gunshot injury to the dominant upper limb whereas 33% cases had injury to the non-dominant upper limb. Out of a total of 18 cases, 2 patients had hypovolemic shock at presentation. One of these had a severed brachial artery. Four cases had associated radial nerve injury. Combined vascular and neurological injury was not present in any of the cases. None of the cases had any associated systemic or visceral injury making them unfit for definitive management of fracture. One patient had bullet engaged in the chest wall without an associated visceral injury and the bullet was retrieved by general surgery team. No patient had sustained injuries to other limbs.

All the cases were taken up for immediate surgery. The mean injury to surgery interval was 3 h and 47 min. Vessel exploration and control of haemorrhage in the patient with brachial arterial injury was carried out by vascular surgeon and reconstruction with reversed great saphenous vein autograft was carried out following bony stabilisation with internal fixation (Fig. 1). Four patients with radial nerve injury underwent debridement and fixation, regardless of the nerve injury. Contused radial nerve was noted in one patient and partially transected and completely transected radial nerves were noted in two others—these were tagged.

Fig. 1 Gunshot fracture of humerus distal diaphysis injuring brachial artery. **a** Preoperative image, **b** preoperative radiograph, **c** postoperative radiograph

In the fourth case with radial nerve injury, the nerve was not visualised during surgery and no active attempt was made to seek it. Definitive nerve exploration and repair for the two transections were carried out by reconstructive surgeons at a higher centre 4 weeks following index surgery. The contused and the un-explored radial nerve injuries were managed expectantly.

Internal fixation was performed with a 4.5 mm narrow titanium locked compression plate in nine cases (50%), proximal humerus anatomical plate in five cases (27%) (Fig. 2), and distal humerus locking plates in four cases (22%). One of the cases had a non-reconstructable fracture of humeral head along with diaphyseal fracture of the humerus. The head fragments were excised piece-meal and diaphyseal fracture was fixed (Fig. 3). Surgical approaches used depended upon the open wound and fracture configuration. Deltopectoral approach was used for proximal humerus fractures whereas diaphyseal fractures were fixed using either anterior or posterior approaches. All the distal humerus fractures were operated using the trans-olecranon approach. Ulnar nerve transposition was performed routinely in these cases. For all cases, range-of-motion exercises were encouraged from as early as the first post-operative day.

Primary closure of the wound could be done in 11 cases (61%). Shoe lace sutures were utilised for delayed primary closure of the wound in three cases (17%). Secondary closure was resorted to in four cases (22%). Of these, negative pressure wound therapy was applied in one patient for 5 days and three cases needed split skin grafting for wound

coverage. Three cases (17%) with features of early wound infection were managed with repeat wound debridement and continuation of intravenous antibiotics for 2 weeks empirically. They responded well but were given oral Linezolid 600 mg po bd for another 4 weeks.

Follow-up period for our study group ranged from 25 to 36 months with a mean follow-up of 28.5 months including telephonic follow-up with radiographic images. Thirteen fractures were noted to have united at 4 months' follow-up visit. Three cases (17%) showed evidence of delayed union with poor callus formation. These cases were managed with autologous bone grafting and were further reviewed at 3 months following the procedure. All the three cases displayed fracture consolidation. Two cases (11%) were found to be in "non-union" with no callus formation at the 4 months' follow-up visit. Decortication and bone grafting was done for both at 17th and 18th week while retaining the implants. Both the fractures were consolidated at 3 months following repeat surgery. The patient with arterial repair went on to have an uneventful post-operative recovery (Fig. 4). The two cases with radial nerve injury who underwent radial nerve repair showed good results with grade four power at finger and wrist extensors at 6 months follow-up visit. Also, pin prick sensation in autonomous zone of radial nerve was recorded. Complete recovery was noted in the other two cases who were managed expectantly suggesting neuropraxia. Two cases (11%) presented with a discharging sinus over the surgical site at 5 and 6 months, respectively, following index surgery. The types of initial wound closure

Fig. 2 Gunshot fracture of proximal shaft of humerus. **a** Wound of entry in close vicinity to neurovascular bundle, **b** wound of exit, **c** preoperative radiograph, **d** postoperative radiograph

Fig. 3 Gunshot fracture of proximal and diaphyseal humerus. **a** Preoperative radiograph showing comminuted fracture humeral head and diaphyseal fracture. **b** The entry wound before debridement, **c** the retrieved bullet, **d** humerus head fragments excised in piece-meal, **e** postoperative radiograph

Fig. 4 Two years follow-up of the case shown in Fig. 1 above. **a** Radiograph showing consolidated fracture, **b–d** show well-taken up split thickness graft with no deformity and satisfactory range of motion at elbow and shoulder joint

in these cases were primary and secondary closure with SSG, respectively. None of these patients had shown any sign of superficial infection earlier. In both the cases, fracture consolidation was noted and they were managed with implant removal alone. Further review at 3 months following

implant removal showed no evidence of residual infection clinically or radiologically. None of the patients displayed any effects of retained bullet subsequently.

Patients with fractures involving the proximal humerus had poorer range of motion at their shoulder joints. The

patient who underwent excision of the humeral head and was unwilling for any further intervention showed 40° of active abduction at shoulder joint at 2 years follow-up. However, full range abduction was possible with assistance (Fig. 5). All the fractures united and no patient was left with residue of infection upon completion of this study. All the studied variables and outcomes obtained have been summarised in Table 1.

Discussion

Although we kept our options regarding internal or external fixation open prior to surgery and the decisions were taken intraoperatively, we did not need to resort to external fixation in any of our cases. The only patient with associated vascular injury was managed with joint intervention wherein the bony stabilization was performed before vascular repair. In most of the cases, wound closure could be achieved either primarily or in a delayed primary manner. However, split skin grafting and negative pressure wound therapy were also

resorted to. We did not need full thickness flap cover for any of the cases.

We could achieve union in all the cases. However in our study, we utilised secondary procedures early to achieve union in five cases. Our cumulative rate of delayed union is 16.66% and that of the non-union is 11.11%. Our delayed infection rate has been 11% with 2 out of 18 cases developing it which could be managed with implant removal following fracture consolidation. Upon including early infections to this figure, our cumulative infection rate becomes 27%. All cases of early infections could be tackled with debridement and intravenous antibiotics for 2 weeks followed by oral antibiotic, with no long-term sequelae.

In the presented study, two cases of nerve injury did not require any intervention and showed complete recovery spontaneously. Also, the two cases with structural lesions of the nerve managed with nerve repair at 4 weeks showed satisfactory recovery at the 6 months' follow-up visit.

Involvement of upper extremity has been witnessed more commonly in gunshot injuries. Research publications regarding management of gunshot fractures of the humerus had become available even before the First World War [2]. It

Fig. 5 30 months follow-up of the case shown in Fig. 3 above. **a** Healed surgical scar, **b** radiograph showing consolidated diaphyseal fracture with absent humeral head, **c** active abduction of 40°, **d**

assisted abduction full range, **e** passive flexion of 120°, **f** active extension of 30°, **g** active internal rotation near full range, **h** active external rotation 50°

Table 1 Summary of distribution of multiple variables amongst the study group ($n=18$) and the outcome measures for the study group; and their distribution

S. no.	Variables/outcome	Types	Numbers
1	Type of fracture	Gustillo Anderson type III a Gustillo Anderson type III b Gustillo Anderson type III c	15 02 01
2	Anatomical region affected	Proximal humerus Diaphysis Distal humerus	02 12 04
3	Surgical approaches	Deltpectoral approach Anterior approach Posterior approach Trans-olecranon approach	05 05 04 04
4	Implants used	Proximal humerus locking plate 4.5 mm narrow LCP Distal humerus locking plates	05 09 04
5	Closure	Primary closure Delayed primary closure Negative pressure wound therapy Split skin grafts	11 03 01 03
6	Radial nerve injury	In-continuity Incomplete laceration Complete rupture	02 01 01
7	Vascular injury	Brachial artery injury	01
8	Infection	Early infection Delayed infection	03 02
9	Union	Union Delayed union Non union	13 03 02
10	Delayed/non union	Autologous bone grafting $\pm$ decortication	05
11	Elbow joint	Fixed flexion deformity Mean arc of motion	10–40° 130°
12	Shoulder joint	Mean flexion Mean abduction Mean external rotation Mean internal rotation	155° 151° 74° 55°

is noteworthy that most of the available literature till date deals with low velocity gunshot fractures of the humerus. No study is available regarding the management of such injuries using internal fixation exclusively [3]. Although the basic principles of management of such fractures remain the same, high velocity gunshot wounds are associated with greater soft tissue disruption along with larger area of contamination and comminution; as a minor increase in the velocity of the projectile increases its kinetic energy exponentially and consequently the damage.

Gunshot injuries should be treated as a separate clinical entity from open humerus fractures caused by other mechanisms [4]. The treatment options for various gunshot fractures range from non-operative to primary internal fixation [5]. Various studies [6] have recommended treatment based upon the grade of open humerus fractures. Conservative management with functional bracing has been recommended for grade I injuries whereas operative or non-operative treatment for grade II open humerus fracture has been recommended based upon the level of

contamination. Operative management has been suggested for grade III open fractures. There are many proponents of conservative management of gunshot fractures of the humerus despite of being an open fracture [7]. Dougherty et al. suggested use of external fixation for contaminated open humerus fractures as a temporizing measure as well as definitive management [8]. Suzuki et al. studied the conversion of external fixation to internal fixation and reported union in 88% of cases in 11.1 weeks [9]. However, a prospective study conducted on the victims of gunshot wounds by Keller et al. in year 1991, showed higher rates of complications with external fixation as compared to bracing. The non-union rate with external fixation was 71.5% as compared to 14% with bracing. However, their results could have been affected by the delayed presentation (mean delay 9.5 days) and higher rates of local infection at the initial presentation (89%) of the patients. They obtained good results with functional bracing. Nonetheless, the authors also reported that patients treated with external fixation and traction had sustained more severe

injuries. In other studies, with external fixation in upper limb injuries, the non-union rates have varied from 5 to 62% [7].

Primary internal fixation for gunshot fractures similar to our study were studied by Wild et al. and they obtained poor results [10]. Connolly et al. [6] studied primary internal fixation in open humerus fracture due to all causes in 46 patients and reported good results with mean union time of 18.4 weeks in 40 patients. They reported delayed union in six patients. Our results outstand all of the above mentioned studies with similar or better fracture union rates and infection rates with reduced number of interventions.

Gunshot wounds are not sterile in nature and auto sterilisation of bullets is a myth [11]. Oral cephalosporin has been recommended for low velocity gunshot injuries whereas intravenous cephalosporin with aminoglycoside have been recommended for high velocity gunshot injuries [12]. Additionally Penicillin has been recommended for use in cases of soil contamination. Our protocol included intravenous metronidazole for anaerobic cover apart from third generation cephalosporin and aminoglycoside for 72 h postoperatively. Antibiotic with anti-psudomonal activity has been recommended for war injuries [4]. Oral Linezolid has been used in our study in cases of infection.

The extent of soft tissue injury is an important determinant of the recovery and useful functionality of the limb [13]. All gunshot fractures have been classified as Gustillo Anderson grade III fractures and aggressive surgical management has been suggested in the literature. With advancement in surgical techniques and early administration of antibiotics, primary closure of the wound has become safer. Early 'Fix and Flap' technique endorsed by various surgeons has obtained good results. It helps in avoiding multiple subsequent surgeries and hence lowers the cost of treatment. The chances of complications increase with increasing trauma to surgery interval [14]. Soft tissue management is the major determinant of the duration of hospital stay in such patients and aggressive wound management resulted in a shortened hospital stay. Neural injuries have been cited to be the most important factor in regaining useful function and the persistence of long-term disability. Kumar et al. [15] performed free flaps for open fractures sustained in battle fields following repeated debridement in 26 cases with a remarkable success rate of 96% with the infection rate of 8 percent. The mean delay for the recipient site to be ready for grafting was 31 days. Though we did not need full thickness flap but split skin grafting was needed for three cases. One case was treated with negative pressure wound therapy for 5 days.

The incidence of nerve injury ranges from 0–58% in the literature [3]. Neuropraxia or axonotmesis is the usual injury observed in low velocity gunshot wounds whereas complete transection is more likely in high velocity gunshot injuries

[16]. Expectant management without nerve exploration has been indicated for isolated nerve injury. However, when associated with vascular injury, disruption of the nerve is more likely and immediate exploration is indicated [17]. Associated peripheral nerve injuries should not guide the treatment plan of operative vs. conservative therapy [18]. Exploration of affected nerve during operative management is also of questionable value as most nerves explored in various studies were found to be in continuity. The timing of repair of transected nerves in such injuries has been suggested as 2–3 weeks as this period allows adequate management of primary injury, debridement, control of infection and soft tissue cover [19]. In our study, two cases had neuropraxia and showed complete recovery spontaneously. Also, the other two recovered satisfactorily following intervention at 4 weeks with complete function at 6 months.

Incidence of vascular injuries in gunshot wounds of the upper limb ranges from 0–15% [20]. Coexisting vascular injury warrants immediate integrated intervention. The order of intervention—whether vascular repair first or fixation first remains a debate. Vascular repair before fixation gives the advantage of relieving the most crucial factor of limb ischemia and improves the chances of limb salvage. Bony stabilisation before vascular intervention ensures that the subsequent orthopaedic procedure does not jeopardize the repair [12]. McHenry et al. [21] demonstrated that vascular repair prior to an orthopaedic procedure was associated with lesser complications and a shorter hospital stay. In the presented study group, we had only one patient with associated vascular injury. Bony stabilization was performed before vascular repair in this patient.

The limitation of the presented work is non-homogeneity of the study population. We have included all the fractures of the humerus in our study group irrespective of the part of the bone involved. Blood supply of the humerus varies in different parts of the bone, being most precarious in distal third of the shaft, the most common site of delayed and non-unions [22]. Having stated that, we should also keep in mind that though proximal, diaphyseal and distal humerus fractures are essentially different injuries and affect adjacent joint functions differently, the primary variables of interest in the presented study were union rates and infection rates. Irrespective of the location of the fracture, the mean time to union in our study was 19 weeks. Primary plate osteosynthesis makes our study unique as no other study discusses plating for open fractures exclusively [3]. We were able to achieve good results with reasonably few complications in the presented study. However due to a small sample size, definitive conclusions could not be drawn to support primary internal fixation in high energy gunshot wounds of the humerus. Nonetheless, we feel that in gunshot wounds presenting within 6 h of injury, primary plate osteosynthesis following thorough debridement is definitely a treatment

option. Based upon our results, further studies are recommended to establish it as a standard of care.

Conclusion

High velocity gunshot fractures of the humerus are common in military conflict zones. They have been associated with remarkable morbidity irrespective of the interventions offered. In the presented study, timely presentation of the patient to emergency room, adequate debridement and soft tissue management along with primary internal fixation could offer satisfactory fracture union rates and infection rates. Primary osteosynthesis has also been helpful in reducing the morbidity and costs incurred in repeated surgeries for such injuries. Associated vascular impairment necessitates multi-speciality intervention on an emergent basis. Nerve injuries may be safely tackled in a staged procedure. We could obtain reasonable results for such injuries, but further studies are warranted to substantiate the practice.

Patient Declaration

The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient(s) have given their consent for their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Compliance with Ethical Standards

Conflict of interest Manoj Kumar, J. P. Khatri and C. M. Singh declare that they have no conflict of interest.

Ethical standard statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed consent For this type of study informed consent is not required.

References

- Chapman, M. W., & Mahoney, M. (1979). The role of early internal fixation in the management of open fractures. *Clinical Orthopaedics and Related Research*, 138, 120–131. (PubMed PMID: 445893).
- Eastman, J. R. (1917). Gunshot fractures of the shaft of the humerus. *JAMA*, LXIX, 251–256. <https://doi.org/10.1001/jama.1917.02590310003002>
- Dougherty, P. J., & Soheil, N. (2006). Gunshot humerus shaft fractures. *Techniques in Orthopaedics*, 21, 214–217. <https://doi.org/10.1097/01.bto.0000240297.49428.d7>
- Sari, A., Ozcelik, I. B., Bayirli, D., et al. (2020). Management of upper extremity war injuries in the subacute period: A review of 62 cases. *Injury*. <https://doi.org/10.1016/j.injury.2020.08.028>
- Khatri, J. P., Kumar, M., & Singh, C. M. (2020). Primary internal fixation in open fractures of tibia following high-velocity gunshot wounds: A single-centre experience. *International Orthopaedics*, 44(4), 685–691. <https://doi.org/10.1007/s00264-019-04387-x>
- Connolly, S., McKee, M. D., Zdero, R., Waddell, J. P., & Schmitsch, E. H. (2010). Immediate plate osteosynthesis of open fractures of the humeral shaft. *Journal of Trauma*, 69, 685–690.
- Karas, E., Strauss, E., & Soheil, S. (1995). Surgical stabilization of humeral shaft fractures due to gunshot wounds. *Orthopedic Clinics of North America*, 26, 65–73.
- Dougherty, P. J., Silverton, C., Yeni, Y., Tashman, S., & Weir, R. (2006). Conversion from temporary external fixation to definitive fixation: Shaft fractures. *Journal of American Academy of Orthopaedic Surgeons*, 14, S124–S127.
- Suzuki, T., Hak, D. J., Stahel, P. F., Morgan, S. J., & Smith, W. R. (2010). Safety and efficacy of conversion from external fixation to plate fixation in humeral shaft fractures. *Journal of Orthopaedic Trauma*, 24, 414–419.
- Wild, J. J., Hanson, G. W., Bennett, J. B., et al. (1982). External fixation use in the management of massive upper extremity trauma. *Clinical Orthopaedics*, 164, 172–176.
- Prat, N. J., Daban, J. L., Voiglio, E. J., & Rongieras, F. (2017). Wound ballistics and blast injuries. *Journal of Visceral Surgery*, 154(Suppl 1), S9–S12. <https://doi.org/10.1016/j.jvisc.surg.2017.07.005>
- Tosti, R., & Rehman, S. (2013). Surgical management principles of gunshot related fractures. *Orthopedic Clinics of North America*, 44(4), 529–540. <https://doi.org/10.1016/j.ocl.2013.06.006> (Epub 2013 Aug 1. Review. PubMed PMID: 24095069).
- Gustilo, R. B., & Anderson, J. T. (1976). Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: Retrospective and prospective analyses. *Journal of Bone and Joint Surgery*, 58A, 453–458.
- Ignatiadis, I. A., Mavrogenis, A. F., Igoumenou, V. G., Polyzois, V. D., Tsiampa, V. A., Arapoglou, D. K., et al. (2019). Gunshot and blast injuries of the extremities: A review of 45 cases. *European Journal of Orthopaedic Surgery and Traumatology*, 29(2), 295–305. <https://doi.org/10.1007/s00590-018-2350-4>
- Kumar, A. R., Grewal, N. S., Chung, T. L., et al. (2009). Lessons from the modern battlefield: Successful upper extremity injury reconstruction in the subacute period. *Journal of Trauma*, 67, 752–757.
- Secer, H. I., Daneyemez, M., Tehli, O., et al. (2008). The clinical, electrophysiologic, and surgical characteristics of peripheral nerve injuries caused by gunshot wounds in adults: A 40-year experience. *Surgical Neurology*, 69, 143–152.
- Bercik, M. J., Kingsbery, J., & Ilyas, A. M. (2012). Peripheral nerve injuries following gunshot fracture of the humerus. *Orthopedics*, 7(35), e349–e352. <https://doi.org/10.3928/01477447-20120222-18> (PubMed PMID: 22385445).
- Omid, R., Stone, M. A., Zalavras, C. G., & Marecek, G. S. (2019). Gunshot wounds to the upper extremity. *Journal of American Academy of Orthopaedic Surgeons*, 27(7), e301–e310. <https://doi.org/10.5435/JAAOS-D-17-00676>
- Moore, A. M., Wagner, I. J., & Fox, I. K. (2015). Principles of nerve repair in complex wounds of the upper extremity. *Seminars in Plastic Surgery*, 29, 40–47. <https://doi.org/10.1055/s-0035-1544169>
- Dougherty, P. J., Vaidya, R., Silverton, C. D., et al. (2009). Joint and long-bone gunshot injuries. *Journal of Bone and Joint Surgery American Volume*, 91, 980–997.

21. McHenry, T. P., Holcomb, J. B., Aoki, N., et al. (2002). Fractures with major vascular injuries from gunshot wounds: Implications of surgical sequence. *Journal of Trauma*, 53, 717–721.
22. Pidhorz, L. (2015). Acute and chronic humeral shaft fractures in adults. *Orthopaedics and Traumatology Surgery and Research*, 101(1 Suppl), S41–S49. <https://doi.org/10.1016/j.otsr.2014.07.034> (Epub 2015 Jan 17. Review. PubMed PMID: 25604002).

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.