ARTICOLO ORIGINALE

Rivista Italiana di CHIRURGIA della MANO
2023;60:104-109
https://doi.org/10.53239/2784-9651-2023-17

Incidence of neurovascular compromise and rates of recovery in open pediatric both bone forearm fractures

Incidenza di compromissione neurovascolare e tassi di recupero nelle fratture esposte di avambraccio in età pediatrica

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Summary

Purpose. The management of nerve injuries in open pediatric forearm fractures remains unclear. The purpose of our study was to describe the relative frequency of nerve injuries with open both bone forearm fractures, as well as rates of nerve recovery after injury and the impact of early surgical nerve exploration.

Methods. We retrospectively reviewed 71 patients with open both bone forearm fractures at a tertiary care children's facility between January 1, 2005 and October 31, 2019. We reviewed the medical record for the presence and type of motor nerve injury, injury characteristics, timing of intervention, return to the operating room and presence of limitations in function at follow up. Injury characteristics and outcomes were summarized using univariate statistics.

Results. Ten patients (14%) sustained a concomitant motor nerve injury. Postoperatively, 7 patients demonstrated no limitation in function and complete nerve recovery at a median time of 8 weeks (range: 1-28) after injury. Two patients had persistent nerve deficits at final follow up and one patient left the country before completing follow up. Of the patients with nerve injury, five patients underwent nerve exploration at the time of operative intervention; three patients had nerves that were intact, one patient's nerve was caught in the fracture site, and one patient's nerve was partially lacerated.

Conclusions. Most nerve injuries associated with open forearm fractures recover spontaneously. However, nerve exploration at the time of injury can be justified as nerves can be lacerated upon injury or found incarcerated in the fracture site.
Level of Evidence: IV

Key words: nerve injuries, pediatric forearm fractures,

Riassunto

Scopo. *La gestione delle lesioni nervose nelle fratture esposte dell'avambraccio*

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Conflitto di interessi
Gli Autori dichiarano di non avere alcun conflitto di interesse con l'argomento trattato nell'articolo.

Come citare questo articolo: Bauer AS, Meyer M, Schott T, et al. Incidence of neurovascular compromise and rates of recovery in open pediatric both bone forearm fractures. Rivista Italiana di Chirurgia della Mano 2023;60:104-109. https://doi.org/10.53239/2784-9651-2023-17

pediatrico rimane poco chiara. Lo scopo del nostro studio era quello di descrivere la frequenza relativa delle lesioni nervose con entrambe le fratture dell'avambraccio osseo aperte, così come i tassi di recupero nervoso dopo la lesione e l'impatto della prima esplorazione chirurgica del nervo.

Metodi. *Abbiamo esaminato in retrospettiva 71 pazienti con entrambe le fratture dell'avambraccio osseo aperte in una struttura di assistenza terziaria per bambini tra il 1 gennaio 2005 e il 31 ottobre 2019. Abbiamo esaminato la cartella clinica per la presenza e il tipo di lesione del nervo motorio, le caratteristiche delle lesioni, i tempi di intervento, il ritorno in sala operatoria e la presenza di limitazioni in funzione al follow-up. Le caratteristiche e i risultati degli infortuni sono stati riassunti utilizzando statistiche univariate.*

Risultati. *Dieci pazienti (14%) hanno subito una concomitante lesione del nervo motorio. Dopo l'intervento, 7 pazienti non hanno dimostrato alcuna limitazione nella funzione e il recupero completo del nervo in un tempo mediano di 8 settimane (intervallo: 1-28) dopo la lesione. Due pazienti avevano deficit nervosi persistenti al follow-up finale e un paziente ha lasciato il paese prima di completare il follow-up. Dei pazienti con lesioni nervose, cinque pazienti hanno subito l'esplorazione nervosa al momento dell'intervento chirurgico; tre pazienti avevano nervi intatti, un nervo del paziente è stato catturato nel sito della frattura, e il nervo di un paziente è stato parzialmente lacerato.*

Conclusioni. *La maggior parte delle lesioni nervose associate a fratture aperte all'avambraccio si riprendono spontaneamente. Tuttavia, l'esplorazione del nervo al momento della lesione può essere giustificata in quanto i nervi possono essere lacerati in caso di lesione o trovati in carcere nel sito di frattura.*

Livello di evidenza: IV

Parole chiave: *lesioni nervose, fratture esposte dell'avambraccio*

Introduction

Forearm fractures occur in approximately 1:200 children each year and are one of the most common upper extremity fractures in children [1]. Additionally, forearm fractures account for a large percentage of open fractures in the pediatric population. One large, multicenter study found that 32% of pediatric open fractures were in the radius or ulna, while a separate single-institution study reported 80% of pediatric open fractures to be in the forearm [2,3]. Rates of neurologic injury after open pediatric both bone forearm fractures have been described from 4-14%, with reports of nerves being partially lacerated, perforated, or trapped in the fracture site [4-9].

Traditionally, open forearm fractures in children have been treated with formal operative debridement and fixation, at which time the surgeon could choose to explore the forearm and assess for nerve injury. Over the last decade, however, there has been an increasing trend towards nonoperative management of pediatric open fractures. A recent systematic review of 17 studies involving 1093 pediatric open fractures found a lower rate of osteomyelitis, wound infection, and nonunion in nonoperatively treated open fractures, but cautioned that the quality of available evidence is still quite low [10]. As many institutions move toward nonoperative management of these fractures, the question is raised whether the presence of a nerve injury should help inform the decision to operate, and whether there is a role for nerve exploration at the time of debridement, when a nerve injury is present.

In open pediatric both bone forearm fractures, little is known about predictors of nerve injury, relative rates of nerve injury, rates of nerve recovery, and the role of nerve exploration at the time of surgery. This study aimed to describe the relative frequency of nerve injuries associated with pediatric open both bone forearm fractures, to describe the rate of nerve recovery after injury, and to determine the role for early surgical nerve exploration in open both bone fractures.

Methods

Study design and baseline characteristics

After obtaining institutional review board approval, we performed a retrospective review of all patients between 0 and 19 years of age, treated for an open both bone forearm fracture at a tertiary children's hospital between January 1, 2005 and October 31, 2019.

We queried our electronic medical record for all patients treated for an open forearm fracture or an unspecified forearm fracture of the forearm using the appropriate codes

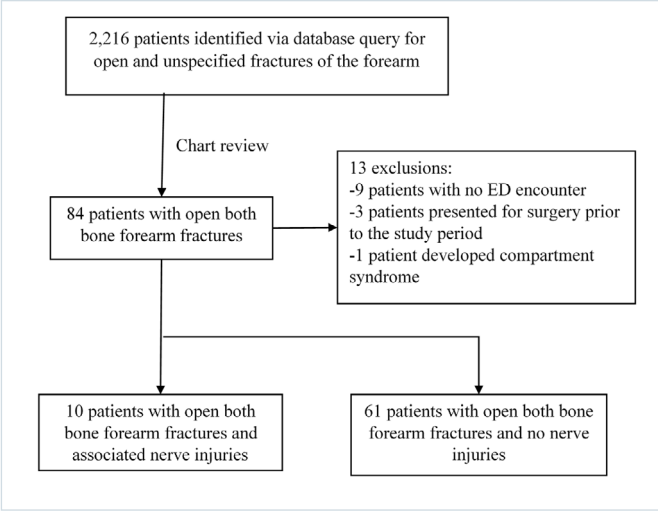

Figure 1. Consort study flow diagram illustrating case inclusion.

from the International Classification of Disease, Ninth and Tenth Revision, and identified 2,216 patients for further review. We excluded patients 19 years old or greater, patients without an emergency room encounter, patients with compartment syndrome, and patients without a documented neurovascular exam before and after treatment. Upon chart review we identified 71 patients with open both bone forearm fractures (Fig. 1).
The average age was 10.6 years (4.1-15.6) and 69 percent were male. Most patients suffered their injury when falling from less than five feet (61%). (Tab. I)

Data collection
The medical record of each patient in the cohort was reviewed. Demographic variables included age and sex. Injury characteristics included the presence and type of nerve injury, mechanism of injury, timing of operative intervention, presence of arterial injury, presence of perfused hand, fracture location of radius and ulna (proximal, middle, or distal third), fracture apex in the coronal and sagittal plane, type of operative fixation, presence of prophylactic fasciotomies, extent of soft tissue injury, return to the operating room and presence of limitations in function at follow up. A nerve was considered injured if motor function innervated by the median, ulnar or radial nerves was documented as absent. Patients with subjective paresthesias but intact motor function were not considered to have a nerve injury given the difficulty interviewing and examining pediatric patients. For patients with an injury to the ulnar, median or radial nerves, we recorded the presence of nerve exploration at the time of operative intervention, the extent of nerve recovery, and the timing of nerve recovery in weeks. Extent of nerve recovery

Table I. Injury and surgery characteristics (N = 71).

Characteristic	Freq.	(%)
Age (years; mean ± SD)	10.6	2.84
Sex (% male)	49	(69%)
Nerve injury	10	(14%)
Ulnar nerve injury	6	(9%)
Median nerve injury	2	(3%)
Radial nerve injury	2	(3%)
Vascular status	70	(99%)
Location of ulnar injury		
Proximal third	1	(1%)
Middle third	36	(51%)
Distal third	34	(48%)
Location of radial injury		
Proximal third	13	(18%)
Middle third	25	(35%)
Distal third	33	(47%)
Mechanism of injury		
Fall < 5 feet	43	(61%)
Fall > 5 feet	24	(34%)
Sports	3	(4%)
Penetrating trauma	1	(1%)
Surgical nerve exploration	6	(9%)
Extent of soft tissue injury		
I	60	(85%)
II	11	(16%)
Operative treatment	70	(99%)
Type of operative fixation used		
Mixed	25	(35%)
Pin	22	(31%)
Plate	19	(27%)
Cast	5	(7%)

SD, standard deviation.

was determined based on review of the clinical notes. Any motor deficit compared to the contralateral limb at the time of final follow up was considered incomplete nerve recovery. Recovery was considered complete if documented or if no deficit was noted at final follow up. Limitation in function was the presence of a complaint related to the injury at final

follow up. Mechanism of injury was categorized as sports, motor vehicle collision, fall from less than 5 feet, fall from greater than 5 feet, penetrating trauma or other. Falls from the monkey bars were considered falls from greater than 5 feet given monkey bars usually stand at least 5 feet off the ground. Extent of soft tissue injury was taken from the operative report and based on the Gustilo-Anderson classification [11]. Presence of arterial injury was considered present if a pulse was absent or an injured artery was discovered intra-operatively. All hands with normal capillary refill in each digit were considered perfused. Timing from injury to operative intervention was estimated based on the history of present illness and timing of operative intervention and then categorized as 0-12 hours, 12-24 hours, and greater than 24 hours. These time periods were chosen because they could be accurately estimated based on the history and timing of surgical intervention. Site and apex of the fractures were collected from review of the radiographs. The data presented here meets the Strengthening the Reporting of Observational Studies in Epidemiology.

Statistical Analysis

Injury characteristics and outcomes were summarized for the cohort. Continuous variables were summarized by mean and standard deviation (SD) or median and interquartile range (IQR), as appropriate. Categorical variables were summarized by frequency and percent. Multivariable logistic regression analysis of predictors of nerve injury was deferred because of our small study cohort.

Results

We examined a total of 71 open forearm fractures; 60 fractures (85%) were grade 1 and 11 were grade 2. Ten patients (14%) suffered a motor nerve injury associated with their open both bone forearm fracture. Ulnar nerve injuries were the most common, occurring in 6 patients (9%). In addition, there were 2 (3%) subjects with a median nerve injury, and 2 (3%) subjects with a radial nerve injury. Fracture location was near evenly split between medial and distal thirds, with only 1 open fracture in the proximal ulna. Most children (61%) sustained their open injuries after a fall from less than 5 feet (Tab. I).

All 71 subjects were treated with irrigation and debridement in the operating room. The fracture edges were irrigated and debrided until deemed clean through extension of the traumatic wound or the approach for fixation depending on fracture location. The vast majority (93%) also underwent operative fixation, consisting of plates and screws, intramedullary rods, or a combination. All patients received antibiotics upon presentation to the emergency room that were continued until 24 hours post-operatively; cefazolin or clindamycin were used in all patients except one who received Unasyn for coverage of flora from a dog bite.

The 10 patients who sustained a nerve injury had their index surgery performed by 10 separate surgeons in our practice. Five patients had their injured nerve explored at the time of operative treatment; while 5 did not. Exploration was performed based on surgeon discretion. Three of the 5 patients who underwent exploration had a nerve that was bruised but intact, one patient's ulnar nerve was found entrapped within the fracture site and a second patient's ulnar nerve was partially lacerated and underwent repair. Postoperatively, 7 of the 10 subjects with nerve injuries (4 ulnar, 2 radial, and 1 median nerve injuries) demonstrated no limitation in function and complete recovery of the nerve at a median time of 8 weeks (range, 1 to 28 weeks) after injury. Three of the 71 subjects (4%) had persistent nerve deficits and limitation in function at the time of final follow up. One patient with a partial ulnar nerve laceration requiring repair at initial surgery had persistent dorsal interossei dysfunction at 20 weeks post-operatively. One patient who suffered a dog bite and was found to have a median nerve deficit but a nerve in continuity at the time of surgery complained of chronic pain, numbness in the median nerve distribution and weakness in forearm at final follow up 67 weeks after intervention. Another patient with an ulnar nerve injury that did not undergo exploration left the country after his three-week post-operative visit, at which time ulnar nerve function had not returned.

Of the 71 open fractures, 45% required a return to the operating room, the majority of which were for removal of hardware. Of the ten patients with nerve injury, 6 (9%) required return to the operating room for removal of hardware. (Tab. II) One patient with nerve injury (1%) required return to the operating room for repeat irrigation and debridement and scar revision in addition to their removal of hardware.

Table II. Outcomes (N = 71).

Characteristic	Freq.	(%)
Returned to operating room	32	(45%)
Limitation in function	3	(4%)
Nerve recovery	9	(13%)
Partial	2	(3%)
Complete	7	(10%)
Timing of nerve recovery (weeks; median (IQR); n = 9)	8	(5-19%)

IQR, interquartile range.

No surgical interventions were required to address nerve deficits. No patients had nerve deficits identified post-operatively.

Discussion

This study of 71 pediatric open forearm fractures found a 14% rate of motor nerve injury. Although the ulnar nerve was the most commonly injured, it is interesting to note that both median and radial nerve injuries were also identified in this cohort. There were no associated vascular injuries in this cohort of type 1 and 2 open fractures. We could not identify predictors of nerve injury amongst patient factors such as age, sex, mechanism of injury, fracture location, or extent of soft tissue injury given our small numbers. Intraoperative procedures varied in our practice, as 5 of the patients underwent nerve exploration at the time of their index procedure, while 5 of the patients did not. Despite this, most subjects did well, with 7 of 10 subjects demonstrating complete nerve recovery at a median of 8 weeks after injury. These findings are similar to the more common scenario of nerve injuries associated with extension-type supracondylar humerus fractures in children. Nerve injuries are seen in approximately 11% of extension-type supracondylar humerus fractures, most of which are not explored, with a similar median time to recovery and high rate of recovery [12].

Our study has limitations. First, we used a retrospective methodology and data reported here was obtained via chart review. Subtle nerve dysfunction at the time of last follow up may be missing, and timing of nerve recovery had to be estimated based on the first post-operative exam with normal nerve function. Second, we were underpowered to detect predictors of nerve injury associated with open both bone forearm fractures given our small numbers, and the literature would benefit from a meta-analysis or multi-center study.

In our series, most patients made a full recovery with only a small number of patients demonstrating residual limitations because of their nerve injuries. This is consistent with other series in the literature. Greenbaum described 62 open pediatric forearm fractures and found that 7 patients had nerve dysfunction identified preoperatively or postoperatively and all nerves recovered with appropriate fracture care. The injured nerves did not require intervention [4]. Haasbeek et al reported their experience with 46 open both bone forearm fractures, identifying three subjects with median nerve injuries and two with combined ulnar and median nerve injuries. All nerve injuries in their cohort recovered, including one child with a degloving injury who underwent acute median and ulnar nerve repairs 5. Luhmann et al reported on 65 open pediatric forearm fractures and found that 9 patients had at least one nerve injured. There were six median nerve, three ulnar nerve and two radial nerve injuries that all improved by two months post-operatively. Injured nerves were only explored if they were encountered during irrigation and debridement [6].

It is difficult to recommend a change in practice based on this series. Our findings support those surgeons who do not routinely explore the nerves in this scenario, given the rarity of these nerve injuries and the high rate of recovery despite only half of patients underwent nerve exploration. However, in the patients who did undergo nerve exploration, one patient was found to have a nerve trapped within the fracture site and a second patient underwent acute repair of an ulnar nerve laceration and these patients went on to full recovery. Given this possibility, those surgeons who routinely explore the nerves in this scenario may continue to feel that exploration is warranted, particularly when the injured nerve is directly in the operative field. Whether acute exploration is performed, it is important to recognize motor nerve injury as a major cause of prolonged recovery after pediatric open both bone forearm fracture. Patients with these injuries require longer postoperative follow-up, and families should be counseled on the risk of incomplete recovery.

References

1 Chung KC, Spilson SV. The frequency and epidemiology of hand and forearm fractures in the United States. J Hand Surg 2001;26:908-915. https://doi.org/10.1053/jhsu.2001.26322

2 Skaggs DL, Friend L, Alman B, et al. The effect of surgical delay on acute infection following 554 open fractures in children. J Bone Joint Surg Am 2005;87:8-12. https://doi.org/10.2106/JBJS.C.01561

3 Iobst CA, Tidwell MA, King WF. Nonoperative management of pediatric type I open fractures. J Pediatr Orthop 2005;25:513-517. https://doi.org/10.1097/01.bpo.0000158779.45226.74

4 Greenbaum B, Zionts LE, Ebramzadeh E. Open fractures of the forearm in children. J Orthop Trauma 2001;15:111-118. https://doi.org/10.1097/00005131-200102000-00007

5 Haasbeek JF, Cole WG. Open fractures of the arm in children. J Bone Joint Surg Br 1995;77:576-581.

6 Luhmann SJ, Schootman M, Schoenecker PL, Dobbs MB, Gordon JE. Complications and outcomes of open pediatric forearm fractures. J Pediatr Orthop 2004;24:1-6. https://doi.org/10.1097/00004694-200401000-00001

7 Federer AE, Murphy JS, Calandruccio JH, et al. Ulnar nerve injury in pediatric midshaft forearm fractures: a case series. J Orthop Trauma 2018;32:e359-e365. https://doi.org/10.1097/BOT.0000000000001238

8 Gainor BJ, Olson S. Combined entrapment of the median and anterior interosseous nerves in a pediatric both-bone forearm fracture. J Orthop Trauma 1990;4:197-199. https://doi.org/10.1097/00005131-199004020-00018

9 Nunley JA, Urbaniak JR. Partial bony entrapment of the median

nerve in a greenstick fracture of the ulna. J Hand Surg 1980;5:557-559. https://doi.org/10.1016/s0363-5023(80)80105-5

10 Singh A, Bierrum W, Wormald J, Eastwood DM. Non-operative versus operative management of open fractures in the paediatric population: a systematic review and meta-analysis of the adverse outcomes. Injury 2020;51:1477-1488. https://doi.org/10.1016/j.injury.2020.03.055

11 Kim PH, Leopold SS. In brief: Gustilo-Anderson classification. [corrected]. Clin Orthop 2012;470:3270-3274. https://doi.org/10.1007/s11999-012-2376-6

12 Shore BJ, Gillespie BT, Miller PE, Bae DS, Waters PM. Recovery of motor nerve injuries associated with displaced, extension-type pediatric supracondylar humerus fractures. J Pediatr Orthop 2019;39:e652-e656. https://doi.org/10.1097/BPO.0000000000001056