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Current Concept Review

Surgical Management of Nerve Injuries Caused by Pediatric Upper Extremity Fractures

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ABSTRACT

While most nerve injuries associated with fractures resolve on their own, there is limited literature regarding the optimal management of persistent palsies. This review outlines nonoperative treatment strategies and provides guidance on the indications and management of cases when surgery is necessary for major upper extremity nerve injuries. It covers indications and techniques for surgical exploration, neurolysis, nerve repair, resection with grafting, and late reconstruction options. We synthesize the existing pediatric and adolescent literature and pertinent adult studies. Furthermore, we share the extensive clinical expertise of the authors, all of whom specialize in pediatric hand and upper extremity surgery.

Key Concepts:

(1) Associated nerve injuries following pediatric upper extremity trauma are uncommon, yet optimal upper extremity function is dependent on prompt diagnosis and referral to a team of hand surgeons and therapists.
(2) Understanding the potential mechanisms/locations of injury and the natural history will enable these teams to diagnose and prognosticate outcomes efficiently.
(3) Physical examination, nerve conduction studies, radiographs, ultrasound, and advanced imaging (MRI) are often required.
(4) Treatment of nerve deficits can include combinations of observation, neurolysis, nerve repair, nerve grafting, nerve transfer, and muscle transfer.

Introduction

When a child presents with an upper extremity fracture accompanied by a nerve injury, the complexity of care increases, along with the stress for all involved. Most fracture-related nerve injuries in the pediatric population occur as neuropraxic stretch injuries [1], which typically resolve over time. If a nerve injury does not show clinical improvement within the first 4–6 weeks, a timely referral to a specialist and further studies may be necessary to understand the underlying issue better. Upon referral, ultrasound and MRI can be utilized for evaluation if there is concern regarding nerve entrapment. Electrodiagnostic studies should be performed if signs of recovery have not appeared by 3–4 months; however, younger children may require sedation for this, in which case the benefits of the study must be weighed against the risks of another anesthesia episode. While additional studies help support the diagnosis, most decisions are based on clinical history, imaging, and physical examination. Management is determined based on the specific injury if surgical intervention is warranted. Surgical options may include exploration and neurolysis, nerve repair, neuroma resection with grafting, nerve transfers, and tendon transfers. This study aims to provide guidance and advice on various techniques for addressing fracture-associated nerve injuries in children, focusing on the three primary nerves in the upper extremity (median, ulnar, and radial), with case examples used to illustrate the different techniques.

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Therapy and nonoperative treatment

When nerve injuries are identified, early referral to a multidisciplinary team that includes a peripheral nerve surgeon and a pediatric occupational therapist or certified hand therapist helps to optimize outcomes. Since persistent nerve injuries may require surgical management—often within six months of the injury—it is ideal to refer the patient within three months or less from the time of injury. The challenge is that children often have difficulty describing their pain or sensory deficits, and motor palsy may be mistaken for a lack of voluntary effort, leading to late recognition. Skilled therapists can recognize nerve deficits and provide interim supportive care while awaiting recovery. Daytime splinting can optimize positioning while allowing for functional mobility. While awaiting radial nerve recovery, a cock-up wrist splint can optimize the position for a power grip and minimize wrist drop. In the case of an ulnar nerve palsy, anticlaw bracing can improve grip (Fig. 1A and B). Children do not develop contractures as quickly as adults; however, certain joints, such as the proximal interphalangeal joints, are unforgiving at any age. Nighttime splinting offers stretching to mitigate contracture without interfering with daytime functioning, such as composite digital/wrist extension splinting for radial nerve palsy or intrinsic-plus splinting for ulnar nerve palsy.

Surgical timing

Most fracture-related nerve injuries occur due to nerve stretching, resulting in a neuroma in continuity. While these injuries often show some progressive spontaneous recovery over one to two years, surgical decisions must be made more promptly. This time sensitivity arises from motor end plate degeneration and muscle atrophy after about one year. Nerve recovery progresses at approximately one millimeter per day (about one inch per month) following an initial healing period of around one month. Consequently, compared to adults, skeletally immature patients face a relatively shorter distance from their nerve lesion to the motor end plate, which reduces recovery time. However, the distance from the nerve lesion to the target motor end plates should be considered to ensure that axonal regeneration reaches them ideally before one year postinjury. The longer the delay between injury and intervention, the lower the potential for recovery. Although the exact timeframe after which nerve grafting or nerve transfer becomes nonviable in the pediatric population is unclear, minimizing the time to referral to optimize surgical timing when indicated is extremely important.

In cases of sharp penetrating trauma, nerve discontinuity should be assumed, and urgent nerve exploration is necessary. Nerve lacerations in this context warrant tension-free repair, which can be achieved acutely by mobilizing the nerve above and below the lesion. While emergent after-hours surgery should generally be avoided, significant delays in treatment beyond 48 hours may reduce the likelihood of performing primary tension-free repair effectively. Gaps can be managed in several ways. Primary coaptation is possible for gaps less than 3 cm using conduit-assisted repair [2], eliminating an additional coaptation site, and avoiding autograft donor site morbidity or the costs associated with allografts. If the gap is too large or if there is a preference for end-to-end coaptation without any gap, autograft or allograft nerve can be used to bridge the gap; however, this introduces an additional coaptation site, which may increase the risk of axonal loss or neuroma formation. Nerve injuries resulting from ballistic trauma constitute a unique subset of penetrating traumas, as the blast force may cause stretch injuries, making immediate exploration not always necessary. With the rising rates of pediatric firearm injuries, there is a growing need for expertise in managing these types of injuries.

Radial nerve

Supracondylar humerus fractures and humeral shaft fractures are common causes of radial nerve injuries in pediatric patients [3,4]. Fortunately, peripheral nerve injuries that do not recover spontaneously in pediatric patients are rare. Shore et al. (2019) demonstrated that 92% of all nerve injuries healed spontaneously after supracondylar humerus fracture [3]. However, the recovery rate for the radial nerve was lower than that for the rest of the study population at 81%. Penetrating trauma and iatrogenic injuries can also lead to radial nerve injuries, which indicate the need for immediate exploration and potential repair. Iatrogenic injury may occur during the surgical fixation of humeral shaft fractures or when fixing medial epicondyle fractures. In the latter situation, the nerve is at risk if a guidewire for a cannulated screw breaches

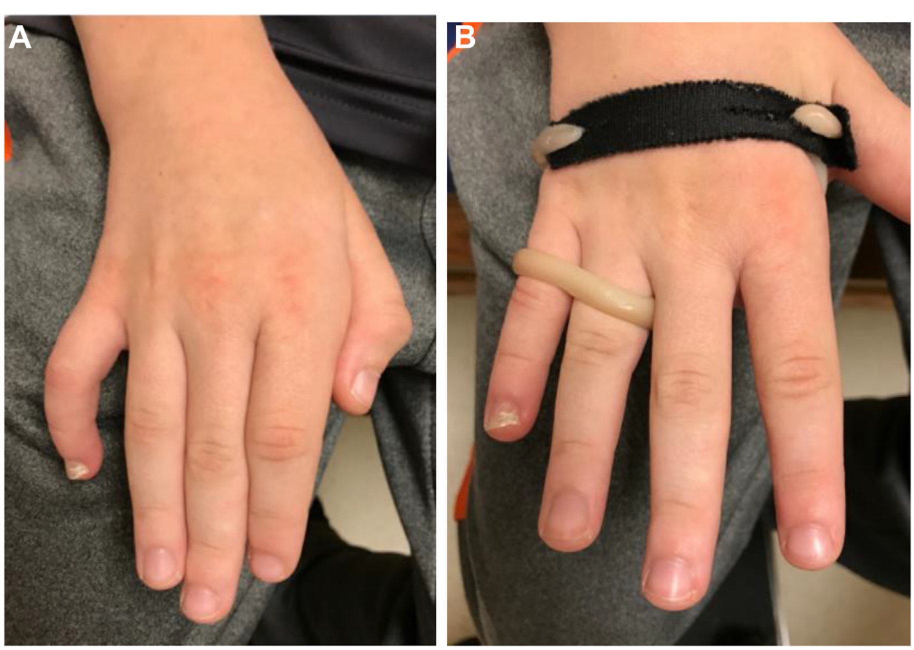

Figure 1. Ulnar nerve palsy causing Wartenberg's Sign (A) and clawing, corrected with a low-profile daytime splint (B) to keep the small finger adducted and prevent MCP hyperextension. (Figures courtesy of Micah Sinclair, MD). MCP, metacarpophalangeal.

the lateral cortex [5]. This is why, although most cannulated screw sets include threaded-tipped guidewires, surgeons often request smooth wires instead (0.045'' wires will fit through most 4.0 cannulated screws).

The detailed anatomy of the radial nerve and the classification of its injury levels are well documented [6] and beyond the scope of this review. Radial nerve injuries can be categorized by location into high and low injuries in relation to the nerve's bifurcation into the posterior interosseous nerve (PIN) and the sensory branch of the radial nerve (SBRN). The latter often leads to the extensor carpi radialis brevis (ECRB) branch distal to the elbow. Clinically, patients with low radial nerve injuries will retain brachioradialis and extensor carpi radialis longus (ECRL) function. Those with high injuries will show no wrist extension. All but the most proximal injuries will preserve elbow extension, while nearly all injuries will denervate the thumb and digital extensors.

Once nonpenetrating radial nerve palsy is identified, supportive care should commence. Daytime bracing of the wrist in slight extension will enable optimal functioning; instead of dealing with a drop wrist, the flexors will be engaged for enhanced grip strength. Nighttime splinting to keep the wrist and finger joints extended will help reduce the development of flexor contractures.

The timing of surgical intervention for the radial nerve is somewhat more forgiving compared to the median and ulnar nerves. This is due to the shorter distance from most lesions to the motor end plates, and reconstructive options such as tendon transfers are effective in cases of ongoing nerve dysfunction. However, restoring primary nerve function is ideal for independent tendon function and sensory recovery. Therefore, recovery that has plateaued at an unacceptable level, along with a lack of a migrating Tinel's sign by six months or sooner, indicates the need for surgical treatment.

Upon exploration, if a neuroma in continuity is encountered and intraoperative nerve stimulation produces a good muscle response, the authors have observed favorable recovery with neurolysis and tetanic nerve stimulation. In cases of nerve discontinuity or a nonstimulating neuroma in continuity, the nerve requires mobilization along with trimming the cut ends or excising the neuroma in continuity to reach healthy-appearing fascicles, respectively. After this, the nerve gap can be evaluated. A single tension-free end-to-end coaptation is ideal; in this scenario, grouped fascicular repair is not indicated for the radial nerve; however, maintaining alignment of matched fascicles during repair is preferred. Unfortunately, significant gapping is often present, especially with chronic injuries. When the benefits of gap reduction through grafting to eliminate tension on the repair outweigh the disadvantages of an additional coaptation site, the sural nerve or medial antebrachial cutaneous nerve can be harvested (Fig. 2A–D), or a processed nerve allograft can be utilized. The precise distance at which the drawbacks of an additional coaptation site with nerve grafting are outweighed by a single yet gapped coaptation site within a conduit remains unknown.

Nerve transfers are a more recent treatment strategy that employs expendable donor branches to reanimate nerves closer to their target. Procedures for restoration of radial motor nerves include the transfer of median to radial nerve branches, specifically a flexor digitorum superficialis (FDS) branch to the ECRB nerve for wrist extension and a flexor carpi radialis (FCR) branch to the PIN for finger and thumb extension. One must consider that this may preclude later use of the denervated FCR

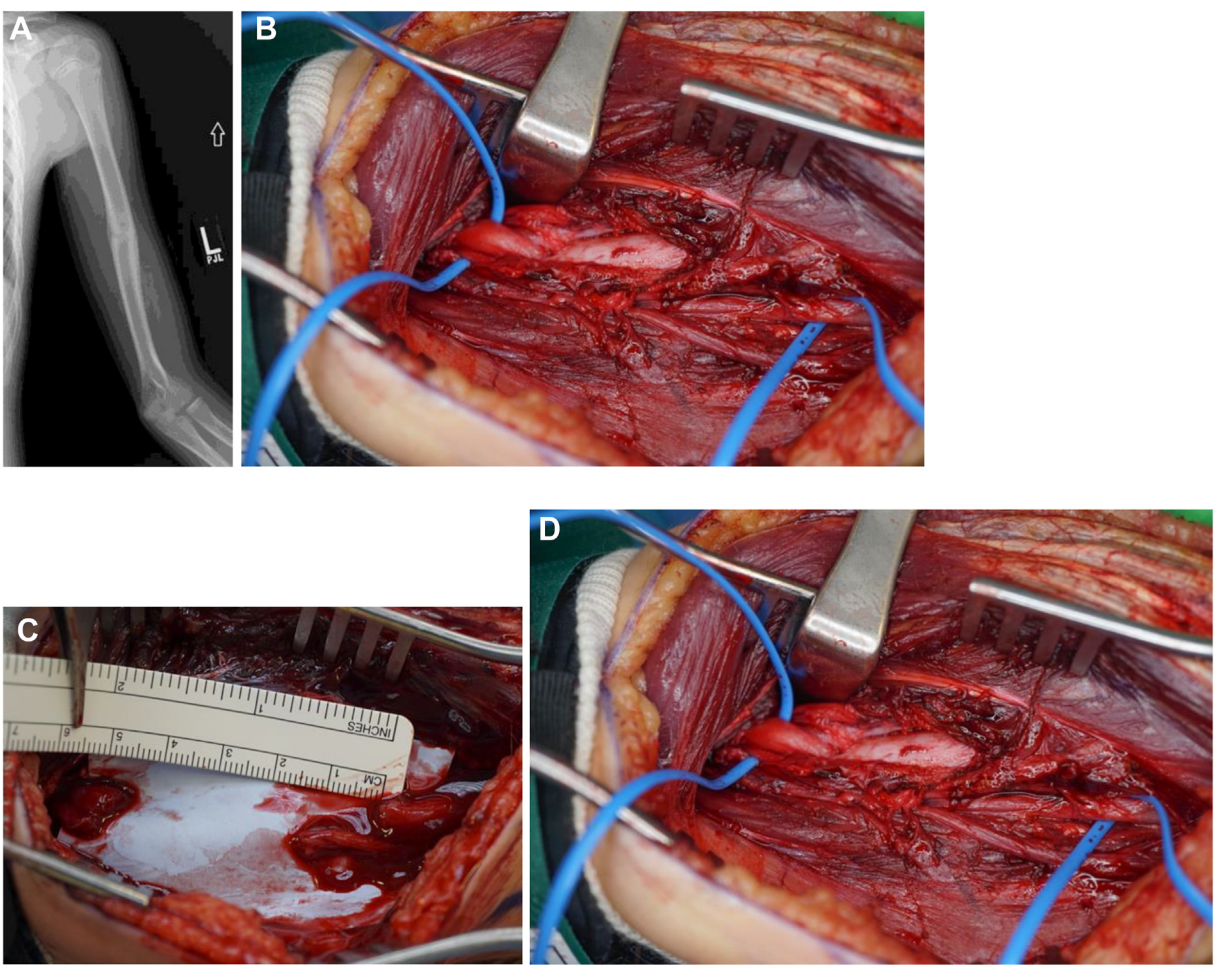

Figure 2. A 12-year-old male sustained a closed humeral shaft fracture with associated radial nerve palsy. X-rays at 3 months demonstrate a healed fracture with lucency indicating probable nerve entrapment (A). Surgical exploration revealed that the radial nerve (loops) was entrapped in the healed fracture site (B). Resection of the damaged nerve tissue produced a 5 cm gap (C), which was managed with a cabled sural nerve autograft (D). (Figures courtesy of Krister Freese, MD).

for tendon transfer should the nerve transfer fail. Additionally, some surgeons have combined tendon and nerve strategies by adding a concomitant pronator teres (PT) to ECRB tendon transfer in an end-to-side fashion to augment wrist extension immediately at the time of nerve transfer [7]. This allows for active wrist extension while awaiting nerve recovery. Choosing an effective strategy relies on patient goals and surgeon expertise. For a patient looking for a quicker path to functional improvement, tendon transfers may be the most suitable surgical option. In contrast, if patients require individual digital extension or fine dexterity, they may benefit more from nerve transfers despite the longer recovery time. Additionally, even with nerve transfers, repairing the primary nerve can help reduce symptomatic neuroma formation and provide some sensory recovery.

Tendon transfers for radial nerve injuries have a long history of success. The goals of tendon transfer surgery are to reestablish extension of the wrist, fingers, and thumb. Tendon transfers cannot restore the function of the first dorsal compartment muscles, abductor pollicis longus (APL) and extensor pollicis brevis (EPB), nor independent extension of the index (extensor indicis proprius) and small (extensor digitorum minimus) fingers. Tendon transfers should obey the classic tendon transfer principles [8]. The PT is transferred to the ECRB to restore wrist extension, selected for its more central insertion at the base of the third metacarpal compared to the ECRL. While the FCR or the flexor carpi ulnaris (FCU) can be transferred to the extensor digitorum communis (EDC) to restore finger extension, our preferred donor is the FCR. In cases of PIN palsy, transferring the FCU would result in the loss of both wrist ulnar deviators, thereby promoting radial deviation of the wrist and diminishing its vital role in power grip. Lastly, the palmaris longus (PL) is transferred to the extensor pollicis longus (EPL). After removing the EPL from the third dorsal compartment, the transfer is conducted in the volar forearm to assist in the radial abduction of the thumb.

In reviewing the limited literature specific to pediatric patients to guide our decision making, Bertelli et al. (2018) showed outcomes of radial nerve grafting in seven pediatric patients with high radial nerve injuries; all patients recovered M4 strength in wrist, finger, and thumb extension [9]. Three of seven patients had a 30° extension lag at the thumb metacarpophalangeal (MCP) joint. They concomitantly reviewed available case reports to show that four of seven patients regained function while the remainder had no recovery. Ray and Mackinnon (2011) reported on 19 adult patients with a mean age of 41 years old, with 18 of 19 subjects achieving good (>M4) recovery of wrist extension and 12 patients gaining good recovery of thumb and finger extension (2 patients gained M3 digital extension) [7]. Recently, Jain et al. (2024) performed a systematic review of nerve grafting, nerve transfers, and tendon transfers [8]. The authors included 29 articles that met criteria and included 754 subjects for pooled analysis. The analysis favored tendon transfers, with 82% achieving a good result. Patients undergoing nerve transfer had a good result in 59% of cases, and those undergoing nerve grafting had good results in 32% of cases. The general results held when wrist and finger extension were evaluated individually. Tendon transfers demonstrated the best wrist and finger extension restoration followed by nerve transfers. Nerve grafting had the highest rates of poor outcomes. These results, however, should be interpreted with caution when deciding on a treatment option for pediatric patients, as all subjects were adults.

Median nerve

Only one-fourth of pediatric median nerve injuries occur from fracture [10]. In children, the median nerve is most commonly injured proximal to the wrist, with lacerations accounting for over half of injuries, and high rates of concomitant tendon and vascular damage. Penetrating trauma is an indication for acute exploration for presumed nerve discontinuity, except for ballistics with a large blast area. Median nerve palsies with a supracondylar humerus fracture, elbow dislocation (3%, higher with concomitant medial epicondyle fracture) [11], and forearm fractures are often neuropraxic stretch injuries [12]; therefore, acute exploration is only indicated if entrapment is suspected or if the onset of the sensorimotor deficit occurred after manipulation. With elbow dislocation, the only initial radiographic sign may be failed concentric reduction with joint widening. After 2–3 months, the anterior posterior radiograph may show a depression in the ulnar distal humeral metaphyseal cortex [13] termed the “Matev Sign.” A neuroma in continuity in this setting can demonstrate impressive induration and swelling; however, detethering and nerve stimulation are the only procedures indicated acutely. Repair is reserved for nerve discontinuity or neuromas lacking recovery after 6 months [12]. If no clinical recovery or migrating Tinel's sign is evident after approximately six weeks, imaging, such as non-sedated ultrasound or MRI, and electrodiagnostic studies may be warranted. These results will inform potential surgical planning based on the location and acuity of the injury.

The median nerve is formed from the medial and lateral cords of the brachial plexus, containing elements of the C5-T1 roots. It travels with the brachial artery through the anteromedial aspect of the arm without branching. In the forearm, the nerve is located between the two heads of the pronator teres, where it sends motor branches to the proximal volar forearm muscles. This is also the location of a potential Martin-Gruber communication, where median nerve branches may innervate ulnar intrinsics; therefore, exploration here should proceed from proximal to distal to visualize the branching pattern and avoid iatrogenic damage. Injuries to the median nerve in the arm or elbow, proximal to the anterior interosseous nerve (AIN), are termed “high,” and have a different treatment algorithm than “low” injuries distal to the elbow.

The deficits from high median nerve injuries (HMNI) differ from the classic sensorimotor distribution due to crossover. Patients with HMNI tend to maintain M4 pronation at 50°, M5 wrist flexion without lateral deviation, M4 middle finger flexion, over 50% thumb opposition strength, 40% grasp strength, 35% pinch strength, and palmar sensation [14]. Due to the distance between the site of HMNI and the distal sensory

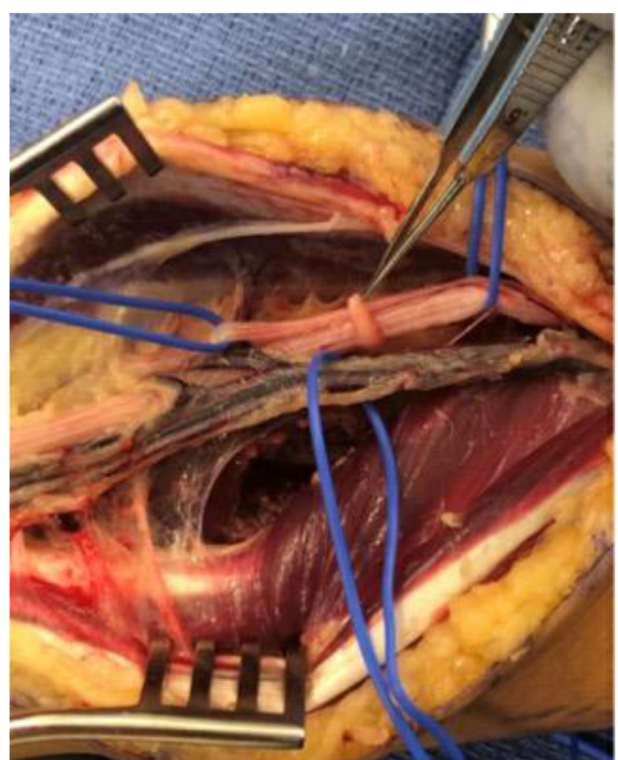

Figure 3. Transfer of the nerve branch from the ECRB (forceps) to the AIN (loop on the left) for the management of median nerve injury. (Figure courtesy of Sonia Chaudhry, MD). ECRB, extensor carpi radialis brevis.

and motor targets, even acute repair does not consistently result in thenar and sensory recovery in adults and older children; however, repair should still be performed to minimize symptomatic neuroma formation. In very young children, depending on the distance from the injury site to the thenar eminence, acute primary repair may enable reinnervation before motor end plate degeneration, particularly with skilled therapy and electrical stimulation in the meantime to keep motor end plates primed. Distal transfers are generally indicated to address weakness in

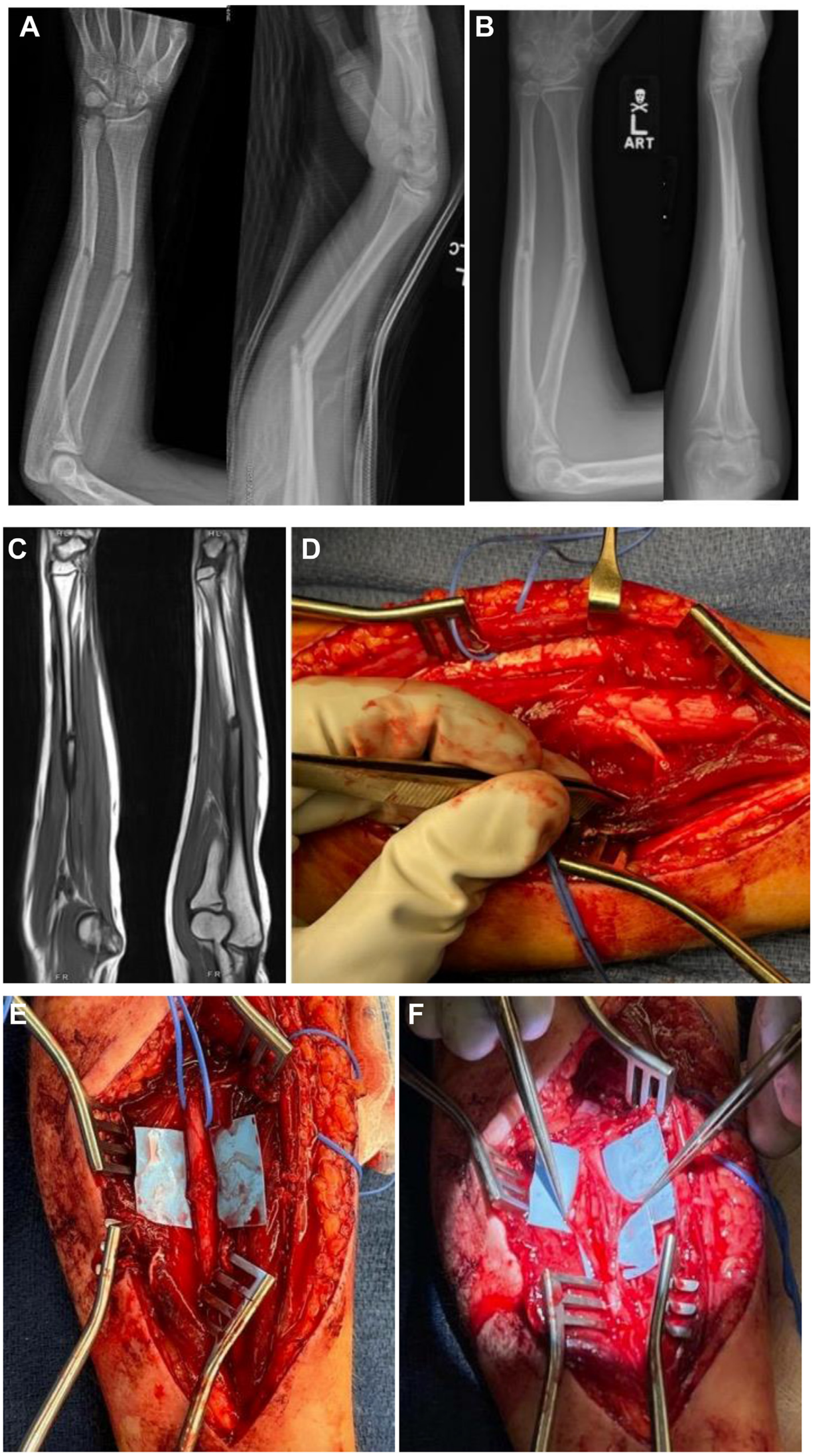

Figure 4. An 11-year-old male sustained a displaced pediatric forearm fracture (A) with median nerve palsy. Though he healed after closed reduction and immobilization, nerve deficit persisted at 12 weeks, and x-rays demonstrated persistent lucency (B). MRI suggested entrapment of the nerve within the fracture site (C), which was confirmed during exploration (D). The nerve was intact after detethering (E), therefore neurolysis and fascicular stimulation were performed (F), with full sensorimotor recovery. (Figures courtesy of Sonia Chaudhry, MD).

pinch, grasp, and opposition, along with sensory deficits affecting the palmar aspect of the distal thumb and the middle and distal phalanges of the index and middle fingers.

Before 12 months after injury, motor reinnervation options include nerve transfers of the supinator branch to an FDS branch, ECRB branch to the AIN, and abductor digiti minimi (ADM) to the thenar branch of the median nerve [14]. The latter applies even in the preserved flexor pollicis longus (FPL), allowing weakened pinch, as intrinsic reinnervation will supplement pinch strength. For anterior interosseous nerve (AIN) reinnervation, the ECRB is considered a more reliable donor than the nerve to the supinator and has offered improvement in grip strength in the author's experience (Fig. 3). After 12–18 months, tendon transfers for FPL and flexor digitorum profundus may be the only option for reanimation. Sensory reinnervation is possible up to 3 years after injury, transferring the dorsal radial sensory nerve branches from the proximal phalanx of the radial side of the index finger and ulnar side of the thumb to their ipsilateral palmar digital nerves [14].

A median nerve palsy associated with a forearm fracture is often presumed to be a stretch neuropraxia and observed. As previously stated, an indication for early imaging is new onset or worsening sensorimotor deficit after manipulation, as this may reveal nerve entrapment or tethering. Late imaging may show a slight lucency in otherwise healed fractures on radiographs (Fig. 4A and B), suggesting nerve entrapment, which MRI can further characterize (Fig. 4C). The "textbook" treatment for a neuroma in continuity that has not recovered after 6 months is resection and repair [12]; however, the authors have had success with neurolysis and tetanic nerve stimulation in subacute injuries where the nerve appeared to be in good condition after detethering (Fig. 4D–F).

When exploration confirms nerve discontinuity or severe persistent neuroma that does not respond to intraoperative nerve stimulation, resection and repair with gap management is indicated. Direct repair has the benefit of only one coaptation site, and this is preferred as long as the repair can be performed without undue tension with a combination of elbow, wrist, and MCP flexion along with nerve mobilization. The author prefers 10–0 nylon epineural suture for direct repair under loupe magnification to allow fascicular alignment with fibrin glue supplementation to seal in the neurotrophic growth factors. Grouped fascicular repair is not generally advised for the median nerve [15] due to the need for intraneural dissection; however, the fascicles should be oriented to match on each end with epineurial repair. With a small gap of 2–3cm in the author's practice, conduit assisted repair can be performed, suturing or gluing the epineurium to the conduit ends, away from the coaptation site. More significant gaps should be bridged with graft, with one children's hospital finding equivalent results between allograft and sural autograft, with shorter operative time in the former; however, this study was limited to neonatal brachial plexus repair [16]. For sural nerve harvest, several transverse "ladder" incisions offer improved aesthetics over a longitudinal "zipper" incision and endoscopic harvest techniques are also described.

Distal median nerve injuries classically present with a "hand of benediction" (Fig. 5). The authors have succeeded with conduit-assisted repair for managing gaps in this area. The high incidence of concomitant tendon injuries and vascular damage to a lesser degree complicates the postoperative immobilization and rehabilitation. Immobilization and detensioning of the coaptation site is more critical than early tendon motion, particularly in children, as more intense therapy or even tenolysis are preferable to a lack of nerve recovery from prematurely stretching the nerve coaptation. The author prefers a long arm cast with the elbow flexed at 90°, wrist and MCP joints flexed about 45°, for 3–4 weeks in children under 6–7 years of age. Even if elbow flexion is not required for gap management, it is included as short arm splints and casts routinely slip off in younger children. Older children can be splinted or casted as one would with adults. Results of low median nerve injuries in children are generally favorable due to shorter reinnervation distances and greater neural plasticity, and younger age correlates with improved sensorimotor recovery, except when the diagnosis is significantly delayed or in more proximal injuries [12,17].

Figure 5. Median nerve palsy classically causes a "hand of benediction" from the finger and thumb extensors being unopposed by the radial flexors, with preserved ulnar-innervated FDP muscles (Figure courtesy of Sonia Chaudhry, MD). FDP, flexor digitorum profundus.

One series of supracondylar humerus fractures referred to a hand therapy unit included 74 children with median nerve palsies. They demonstrated the average nonoperative recovery time to be about 4 months, though 27% still lacked M4 strength by 6 months and 13% at 2 years [18]. In this series, open reduction was associated with a faster recovery of motor function at an average of 80 days vs 151 days. One series of 45 median and/or ulnar nerve injuries (24 isolated median nerves, 11 ulnar nerves, and 10 combined) in the forearm demonstrated 87% recovery in children under 12 and 67% recovery in patients 12–20 years of age, with authors concluding age is a significant factor in functional outcome [19]. While crush injuries on average fare better than lacerations [12]; acute nerve repair with direct suture in one series of 10 children with median nerve lacerations demonstrated all children to have expected or only slight deficit in monofilament sensation and complete strength in long term follow-up, with better sensory recovery under age 12 [20].

Ulnar nerve

Publications reviewing pediatric peripheral nerve injuries have shown ulnar nerve palsies to be the most common acute pediatric mononeuropathy, with trauma as the most common etiology [10,12]. Many surgeons are aware of chronic tardy ulnar nerve palsy related to deformity and dysfunction from lateral humeral condyle nonunion or cubitus valgus associated with supracondylar humerus malunion; however nerve dysfunction is also related to prior medial epicondyle trauma [21,22]. Of acute pediatric ulnar palsies, 1/3 are associated with humerus fractures, including supracondylar and distal humerus shaft fractures (Fig. 6). Casting can immobilize the paralyzed muscles, masking the loss of function and delaying the diagnosis. It is uncommon for children to spontaneously report numbness or tingling of the ulnar digits in the hand, either because their nerve pain is isolated to the elbow region, or they are cognitively unable to describe this sensation. Open injuries or associated penetrating trauma bear special consideration (Fig. 7).

Ulnar nerve palsy also occurs in 10% of flexion-type supracondylar humerus fractures in children, related to the injury or the nerve being stretched over the proximal fragment during fracture displacement [23, 24]. It is well known that it can also be injured iatrogenically during

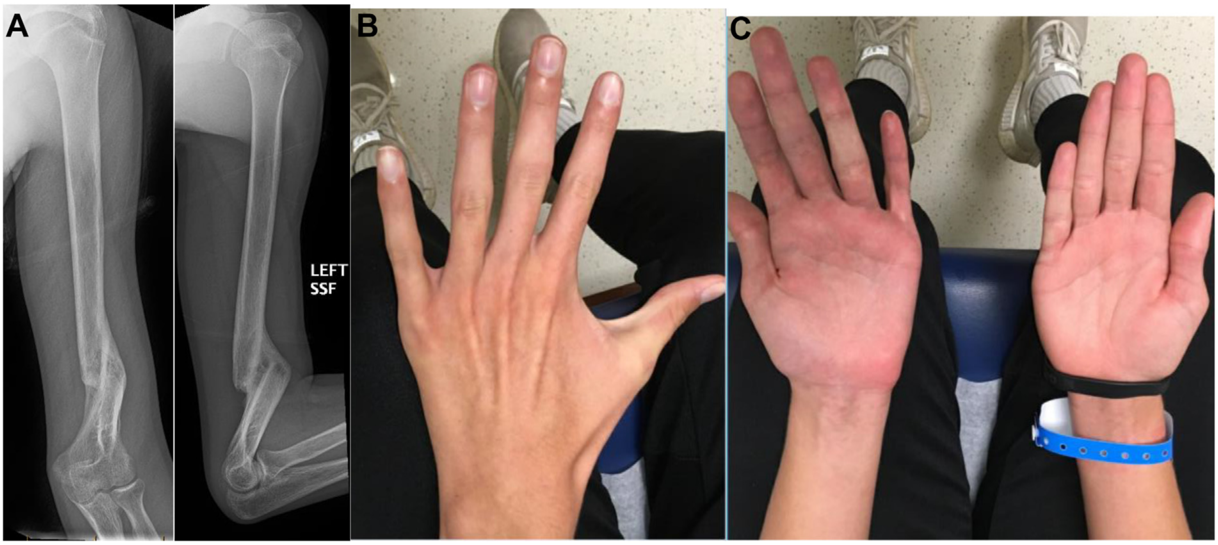

Figure 6. X-rays show a pediatric distal 1/3 humeral shaft fracture healed with nonoperative management (A). A concomitant ulnar nerve palsy eventually led to first dorsal interosseous (B) and hypothenar (C) wasting. This patient had spontaneous resolution of their palsy with full strength and muscle bulk restoration by 1 year postinjury. (Figures courtesy of Micah Sinclair, MD).

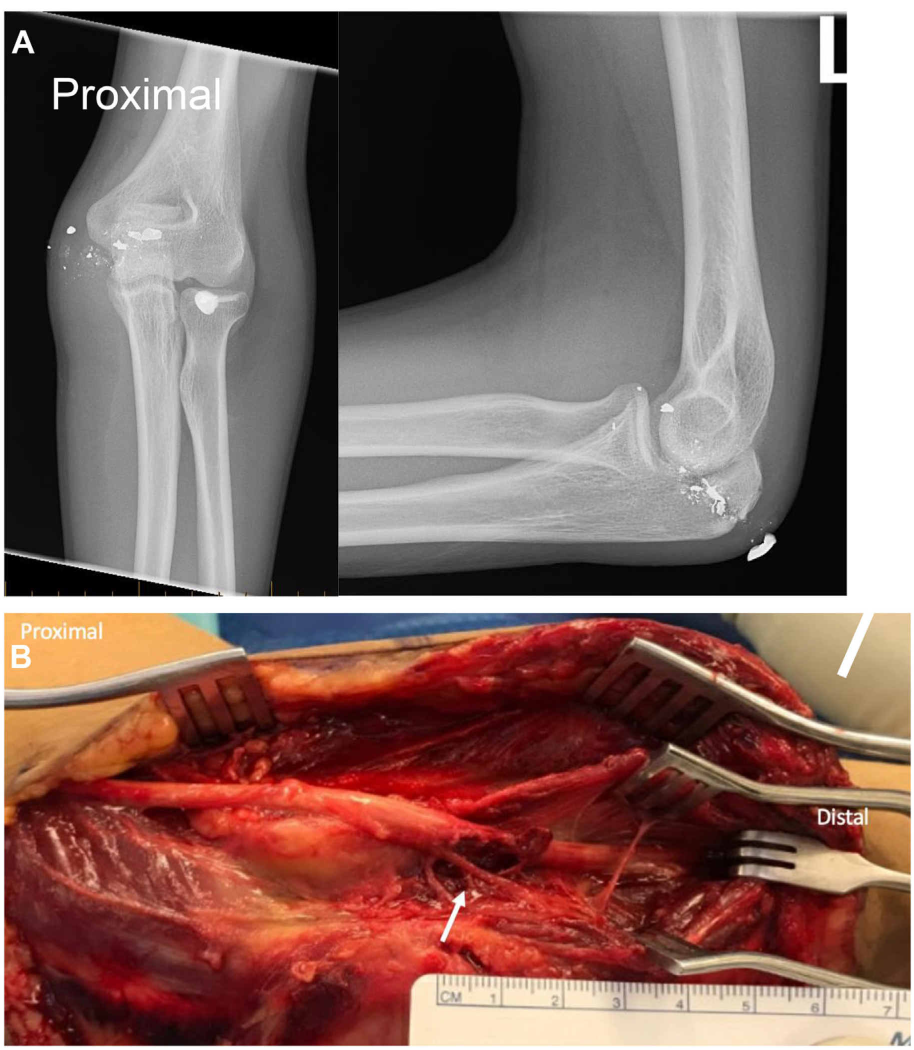

Figure 7. Fourteen-year-old male sustained a gunshot to the medial elbow, causing an olecranon fracture (A). Acute exploration revealed transection of the ulnar nerve with a 2 cm gap (B) managed with nerve grafting and repair. (Figures courtesy of Micah Sinclair, MD).

medial pin placement, mainly due to the potential for undiagnosed subluxation or laxity of the nerve due to fracture deformity. This can be avoided by making a small incision medially and ensuring that the nerve is identified and protected before K-wire placement. Additionally, if treating an intercondylar split with K-wire fixation, when placing a pin from lateral directed medially, one must ensure that the tip of the wire does not penetrate the cubital tunnel. This is a cause for perineural scarring and eventual surgical management for ulnar neuritis.

Posttraumatic ulnar nerve dysfunction can also occur in a delayed fashion. While medial epicondyle fracture management is debated as to whether it requires surgical or nonsurgical management for the bone itself, the degree of displacement may also impact ulnar nerve symptoms immediately or late (Fig. 8). In a study population of patients who had sustained medial epicondyle fractures and had late-onset stiffness and associated ulnar nerve provocative symptoms, successful treatment can be achieved with subcutaneous anterior transposition. Goldfarb evaluated the outcome in medial epicondyle fractures in patients who underwent open reduction internal fixation (ORIF) initially or had a nonunion and found that their range of motion improved by an average of 22° following transposition, and patient-reported outcomes measurement information system (PROMIS) pain interference scores improved significantly [25]. While Goldfarb reports that no evidence of focal ulnar nerve pathology is found, correlated with negative electromyography/nerve conduction study (EMG/NCS) before surgery, it has been an observation that the nerve is either subluxing before release and transposition and often has a visible hourglass deformity where the compression point was located with swelling of the nerve distal to this site.

More distally, the risk of nerve injury in pediatric forearm fractures is relatively low at 0.7%; however, the ulnar nerve is found to be involved 55% of the time [26]. Risk factors include high-energy injuries (82%), both-bone mid-distal fractures (increased nerve tethering compared to more proximal fractures), long oblique patterns, and open injuries [26–28]. Most injuries (94%) fully recover with a mean time to recovery of 4 months (range 1–11 months). One must recognize that the ulnar nerve can be trapped in the fracture site (Fig. 9A), encased in hypertrophic scar tissue or bony callus, or partially lacerated from the ulnar oblique fragment [27]. Most patients have immediate ulnar sensorimotor deficits upon presentation, before reduction. Physical exam findings include loss of intrinsic function with clawing of the ulnar digits, inability to adduct or abduct the digits (Fig. 1A), inability to straighten the interphalangeal joints and numbness in the ulnar digits, and eventually, muscle atrophy visible in the hypothenar eminence and 1st dorsal interosseous (Fig. 6B and C). The injury can be missed due to difficulty in examining the pediatric patient in severe pain; thus, frequent clinical neurologic exams should be performed. The clinical picture can also be confused if the flexor tendons are trapped in the fracture site. An EMG/NCS and/or MRI should be considered if an ulnar nerve deficit persists, at least 3 months postoperatively. If there is no signal on EMG/NCS and recovery is absent, treatment includes nerve exploration and external neurolysis (Fig. 9 B and C) as for other forearm fracture-associated nerve palsies [27,28]. Most of these nerve injuries recover within 4–6 months following neurolysis. An occupational therapist should follow the patient closely during recovery to maintain passive range of motion and begin strengthening when nerve recovery is noted.

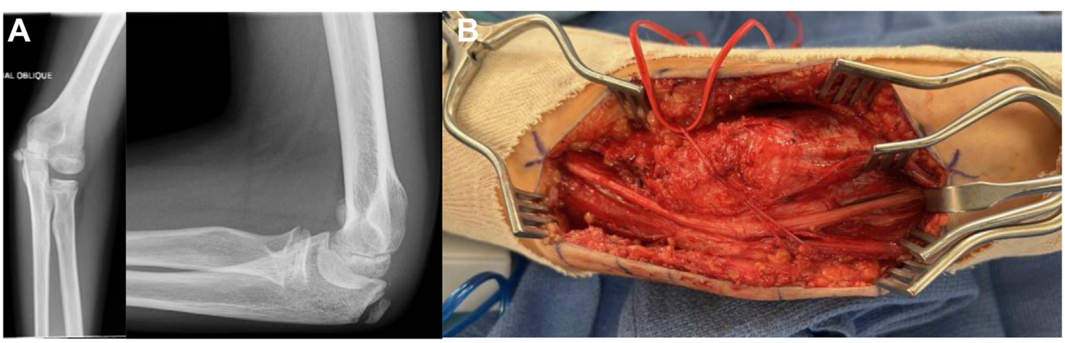

Figure 8. 11-year-old male playing baseball presented with persistent elbow pain as well as ring and small finger numbness and tingling 4 months after sustaining a medial epicondyle fracture shown on AP and lateral X-rays (A) when he presented. At the time of surgery, the ulnar nerve was found to be enlarged distal to the site of compression (B). (Figures courtesy of Micah Sinclair, MD).

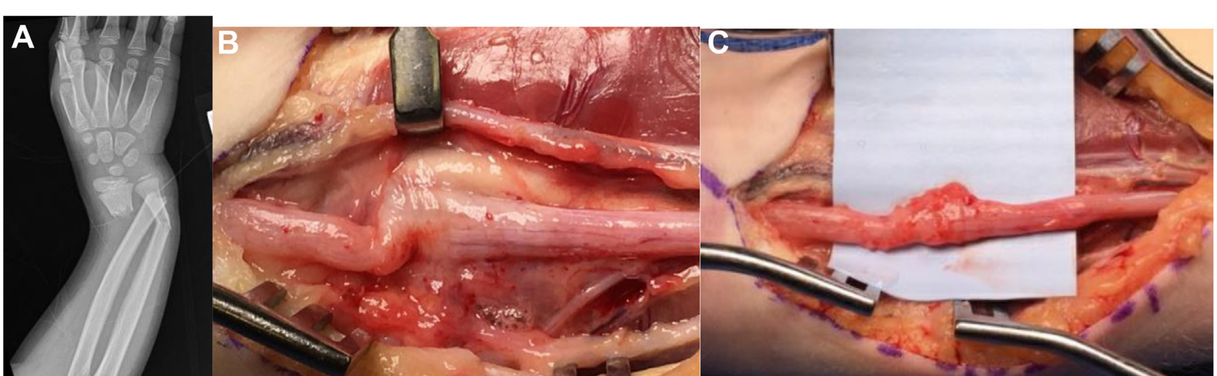

Figure 9. A 7-year-old male sustained a distal radius and ulna fracture (A) accompanied by ulnar nerve palsy, which was managed with closed reduction. Examination at three months showed the nerve encased in the fracture callus of the radius (B), along with the FDP tendons of the ring and small fingers. After detethering (C), the ulnar nerve began to recover. (Figures courtesy of Micah Sinclair, MD).

It is worth mentioning that ulnar nerve pathology can present as isolated posttraumatic stiffness or medial elbow pain, without the classic numbness and/or tingling that radiates to the ulnar digits. This often occurs in athletes with ulnar nerve instability, little league elbow following fixation, medial condyle malunion, or K-wire fixation of intraarticular distal humerus fracture. In these situations, ulnar nerve release and transposition is an effective treatment for symptomatic relief and motion, precluding the need for a joint release for stiffness. In situ release of the ulnar nerve, in symptomatic nerve subluxation, is insufficient to relieve symptoms, and nerve transposition should be performed along with release. This is distinct from asymptomatic ulnar nerve instability, which does not require treatment.

Conclusion

While most pediatric and adolescent injuries do well with standard fracture management, it is essential to note the hallmarks of nerve injury associated with specific fracture patterns. While much of this discussion has focused on surgical management, certain injuries can recover with supportive nonsurgical management. Understanding these injury patterns can allow for improved collaboration and early referral to a hand surgery trained specialist to support the recovery of our patients' functional nerve deficits.

Additional links

- **JPOSNA®**: Diagnosis and Management of Nerve Injuries Caused by Pediatric Uppler Extremity Fractures.

Consent for publication

The author(s) declare that no patient consent was necessary as no images with identifying information are included in the article.

Author contributions

Sonia Chaudhry: Writing – review & editing, Project administration, Conceptualization. **Hilton P. Gottschalk:** Writing – original draft. **Krister Freese:** Writing – original draft. **Micah Sinclair:** Writing – original draft. **Carley Vuillermin:** Writing – original draft.

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Declarations of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Ho CA, Gottschalk H, Samora JB, Freese K, Chaudhry S. Diagnosis and management of nerve injuries caused by pediatric upper extremity fractures. JPOSNA 2023;5(2). https://doi.org/10.55275/JPOSNA-2023-708.

[2] Lin JS, Jain SA. Challenges in nerve repair and reconstruction. Hand Clin 2023; 39(3):403–15. https://doi.org/10.1016/j.hcl.2023.05.001.

[3] 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(9):E652–6. https://doi.org/10.1097/BPO.0000000000001056.

[4] O'Shaughnessy MA, Parry JA, Liu H, Stans AA, Larson AN, Milbrandt TA. Management of paediatric humeral shaft fractures and associated nerve palsy. J Child Orthop 2019;13(5):508–15. https://doi.org/10.1302/1863-2548.13.190012.

[5] Marcu DM, Balts J, McCarthy JJ, Kozin SH, Noonan KJ. Iatrogenic radial nerve injury with cannulated fixation of medial epicondyle fractures in the pediatric humerus: a report of 2 cases. J Pediatr Orthop 2011;31(2):13–6. https://doi.org/10.1097/BPO.0b013e318209287d.

[6] Chaudhry S, Ipaktchi KR, Ignatiuk A. Updates on and controversies related to management of radial nerve injuries. J Am Acad Orthop Surg 2019;27(6):e280–4. https://doi.org/10.5435/JAAOS-D-17-00325.

[7] Ray WZ, MacKinnon SE. Clinical outcomes following median to radial nerve transfers. J Hand Surg Am 2011;36(2):201–8. https://doi.org/10.1016/j.jhsa.2010.09.034.

[8] Jain NS, Barr ML, Kim D, Jones NF. Tendon transfers, nerve grafts, and nerve transfers for isolated radial nerve palsy: a systematic review and analysis. Hand 2024;19(3):343–51. https://doi.org/10.1177/15589447221150516.

[9] Bertelli J, Soldado F, Ghizoni MF. Outcomes of radial nerve grafting in children after distal humerus fracture. J Hand Surg Am 2018;43(12):1140.e1–6. https://doi.org/10.1016/j.jhsa.2018.04.018.

[10] Aman M, Zimmermann KS, Boecker AH, et al. Peripheral nerve injuries in children—prevalence, mechanisms and concomitant injuries: a major trauma center's experience. Eur J Med Res 2023;28(1):1–7. https://doi.org/10.1186/s40001-023-01082-x.

[11] Montanari S, Sartore R, Spina V, Adani R. Post-traumatic entrapment of the median nerve in the ulno-humeral joint: diagnosis, treatment and literature review. J Orthop Sci 2022;27(3):627–34. https://doi.org/10.1016/j.jos.2021.02.006.

[12] Costales JR, Socolovsky M, Sánchez Lázaro JA, Costales DR. Peripheral nerve injuries in the pediatric population: a review of the literature. Part II: entrapment neuropathies. Childs Nerv Syst 2019;35(1):37–45. https://doi.org/10.1007/s00381-018-3975-7.

[13] Matev I. A radiological sign of entrapment of the median nerve in the elbow joint after posterior dislocation. A report of two cases. J Bone Jt Surg - Ser B 1976;58(3):353–5. https://doi.org/10.1302/0301-620x.58b3.956256.

[14] Soldado F, Bertelli JA, Ghizoni MF. High median nerve injury. Motor and sensory nerve transfers to restore function. Hand Clin 2016;32(2):209–17. https://doi.org/10.1016/j.hcl.2015.12.008.

[15] Pederson WC. Median nerve injury and repair. J Hand Surg Am 2014;39(6):1216–22. https://doi.org/10.1016/j.jhsa.2014.01.025.

[16] Hamant LG, Adelson PD, Kang P, Brown SD, Arango JI. Comparison of autograft versus allograft in the surgical repair of pediatric obstetrical brachial plexus injuries. J Neurosurg Pediatr 2020;26(3):318–26. https://doi.org/10.3171/2020.4.PEDS2033.

[17] Langridge B, Griffin MF, Akhavani MA, Butler PE. Long-term outcomes following pediatric peripheral nerve injury repair. J Hand Microsurg 2020;12(1):27–31.

[18] Wilks DJ, Ye X, Biggins R, Wang KK, Wade RG, McCombe D. Median nerve palsy in pediatric supracondylar humerus fractures recovers faster with open than closed reduction. J Pediatr Orthop 2023;43(7):407–13. https://doi.org/10.1097/BPO.0000000000002424.

[19] Chemnitz A, Björkman A, Dahlin LB, Rosén B. Functional outcome thirty years after median and ulnar nerve repair in childhood and adolescence. J Bone Jt Surg 2013; 95(4):329–37. https://doi.org/10.2106/JBJS.L.00074.

[20] Fleurette J, Gaume M, De Tienda M, Dana C, Pannier S. Peripheral nerve injuries of the upper extremity in a pediatric population: Outcomes and prognostic factors | Lésions nerveuses périphériques du membre supérieur chez l'enfant: résultats cliniques à long terme et facteurs pronostiques. Hand Surg Rehabil 2022;41(4):481–6.

[21] Thiyam R, Lalchandani R. Tardy ulnar nerve palsy after fracture non-union medial epicondyle of humerus - an unusual case. J Clin Orthop Trauma 2015;6(2):137–9. https://doi.org/10.1016/j.jcot.2014.12.004.

[22] Rubin G, Orbach H, Bor N, Rozen N. Tardy ulnar nerve palsy. J Am Acad Orthop Surg 2019;27(19):717–25. https://doi.org/10.5435/JAAOS-D-18-00138.

[23] Barrett KK, Skaggs DL, Sawyer JR, et al. Supracondylar humeral fractures with isolated anterior interosseous nerve injuries : is urgent treatment necessary. J Bone Jt Surg - Am 2014;96:1793–7.

[24] Norrell KN, Muolo CE, Sherman AK, Sinclair MK. The frequency and outcomes of nerve palsies in operatively treated supracondylar humerus fractures. J Pediatr Orthop 2022;42(8):408–12. https://doi.org/10.1097/BPO.0000000000002186.

[25] Payne ER, Wall LB, Baker S, Calhoun V, Roberts S, Goldfarb CA. Outcomes of therapy and ulnar nerve transposition for elbow stiffness after pediatric medial epicondyle fractures. J Hand Surg Glob Online 2023;5(6):744–50. https://doi.org/10.1016/j.jhsg.2023.07.002.

[26] Zilliacus K, Nietosvaara Y, Helenius I, Laaksonen T, Ahonen M, Grahn P. The risk of nerve injury in pediatric forearm fractures. J Bone Jt Surg 2023;105(14):1080–6. https://doi.org/10.2106/JBJS.22.01392.

[27] Federer AE, Murphy JS, Calandruccio JH, et al. Ulnar nerve injury in pediatric midshaft forearm fractures: a case series. J Orthop Trauma 2018;32(9):E359–65. https://doi.org/10.1097/BOT.0000000000001238.

[28] Baysefer A, Izci Y, Akay KM, Kayali H, Timurkaynak E. Surgical outcomes of ulnar nerve lesions in children a retrospective clinical study. Pediatr Neurosurg 2004; 40(3):107–11. https://doi.org/10.1159/000079851.