A Mini-Open Approach to Medial Pinning in Pediatric Supracondylar Humeral Fractures May Be Safer Than Previously Thought

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Background: Displaced pediatric supracondylar humeral fractures (SCHFs) are stabilized after reduction by smooth pins. Although some SCHFs are biomechanically stable after lateral-only entry pinning (lateral pinning), an additional medial entry pin (cross-pinning) confers superior stabilization in some SCHFs. There is a recognized risk of iatrogenic ulnar nerve injury with medial entry pinning. The best existing evidence has estimated an iatrogenic ulnar nerve injury rate of approximately 3.4% in cross-pinning. In similar studies, the rate of iatrogenic nerve injury (all nerves) in lateral pinning is estimated at 1.9%. This study aimed to use a large, single-center, single-technique (mini-open) retrospective case series to determine the rate of iatrogenic ulnar nerve injury in cross-pinning.

Methods: Patients undergoing percutaneous cross-pinning via the mini-open technique for SCHFs from 2007 to 2017 were retrospectively reviewed. Injury characteristics, operative variables, fixation technique, and complications, such as iatrogenic nerve injury, were recorded. Patients who underwent operative treatment at another hospital, had no postoperative follow-up, or died due to polytrauma were excluded.

Results: In this study, 698 patients undergoing cross-pinning during the study period were identified. Patients treated with cross-pinning had severe fractures, including a total of 198 preoperative neurovascular injuries (28.4%), 32 patients (4.6%) with skin tenting, and 19 patients (2.7%) with open fractures. Iatrogenic nerve injury was reported in 3 cases (0.43%), all of which affected the ulnar nerve. In 2 of 3 cases of iatrogenic nerve injury, the ulnar nerve symptoms resolved at a mean follow-up of 15 weeks.

Conclusions: The mini-open approach for medial pin insertion is safer than previous estimates. Here, in the largest single-center study of cross-pinning for SCHFs, the iatrogenic ulnar nerve injury rate of 0.43% was nearly 10 times lower than estimated rates from recent meta-analyses. Considering all nerves, the iatrogenic injury rate for this cross-pinning cohort was also lower than the estimated iatrogenic nerve injury rate for lateral pinning.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Displaced pediatric supracondylar humeral fractures (SCHFs) have traditionally been stabilized after reduction by smooth pin fixation[1-3]. The goal of smooth pin fixation is to maintain an appropriate reduction until fracture union without causing iatrogenic injury to any surrounding structures, such as the ulnar, median, or radial nerves, which traverse the elbow joint and are vulnerable to iatrogenic injury from a misplaced pin. The 2 most common pinning techniques are retrograde all-lateral pinning and cross-pinning[4]. Lateral pinning involves the insertion of divergent pins from the lateral condyle to stabilize the fracture. Cross-pinning also utilizes lateral-entry pins but adds an additional pin from the medial epicondyle. Despite offering potentially superior biomechanical stability, cross-pinning is often avoided because of the risk of iatrogenic ulnar nerve injury as a consequence of medial pin insertion[4-6]. The current

Disclosure: The **Disclosure of Potential Conflicts of Interest** forms are provided with the online version of the article (http://links.lww.com/JBJS/G737).

American Academy of Orthopaedic Surgeons (AAOS) clinical practice guideline has the following recommendation[6]: "the physician might avoid the use of a medial pin (strength of evidence: Weak)." However, nerve injury, including injury to the median, radial, and ulnar nerves, also occurs in lateral pinning at a reported rate of 1.9%[7].

Identifying the true risk of iatrogenic nerve injury in the pinning of SCHFs is elusive. Specific to ulnar nerve injury in cross-pinning, techniques for placing the medial pin have varied widely from study to study, ranging from blind palpation and percutaneous placement to placement under direct visualization via a mini-open technique[3,8,9]. Furthermore, some studies have used different definitions of iatrogenic ulnar nerve injury, including both direct violation of the ulnar nerve upon placement of the medial pin and ulnar nerve compression as a delayed result of impingement by the pin on the cubital tunnel[10,11]. Data from multiple small cohorts and randomized controlled trials have shown an iatrogenic ulnar nerve injury rate ranging from 0% to 15%[12-18]. Some meta-analyses, drawing on these varied studies, have estimated a range of approximately 3.0% to 4.1%[12,19,20]. The limitations of small study sizes, variable techniques, and different definitions of iatrogenic ulnar nerve injury combine to make estimating the true risk difficult.

Cross-pinning is still heavily used in practice as it confers better biomechanical stability in certain fracture patterns. There is no consensus on the safest technique for medial pin placement[7,21-23]. As such, consistent data are needed to determine the safest method for cross-pinning. Our longstanding institutional practice has included frequent use of cross-pinning. In this current study, we report the largest single-center, single-technique case series of pediatric patients with SCHF treated with cross-pinning via the mini-open technique. We describe our approach for medial pin insertion using a mini-open technique and determine the rate of iatrogenic ulnar nerve injury using this technique. Furthermore, we sought to better characterize the true clinical implications for the patients who sustain iatrogenic injuries.

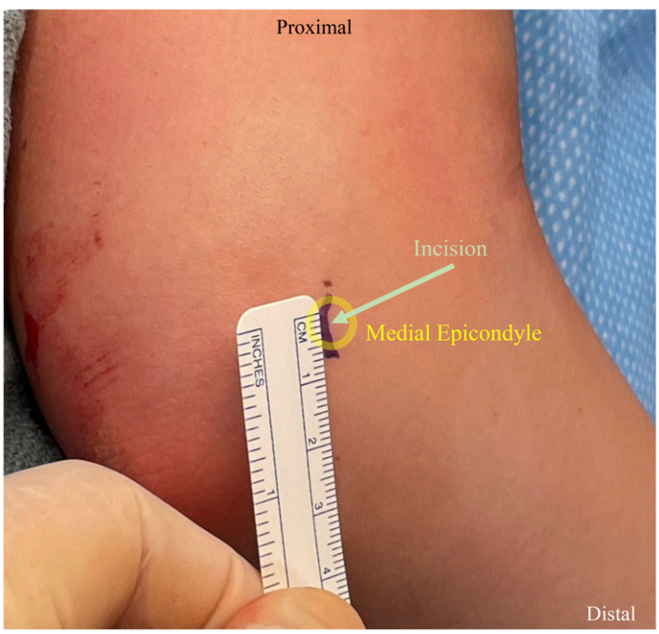

Fig. 1
A small (approximately 1-cm) incision is made directly over, or just anterior to, the medial epicondyle.

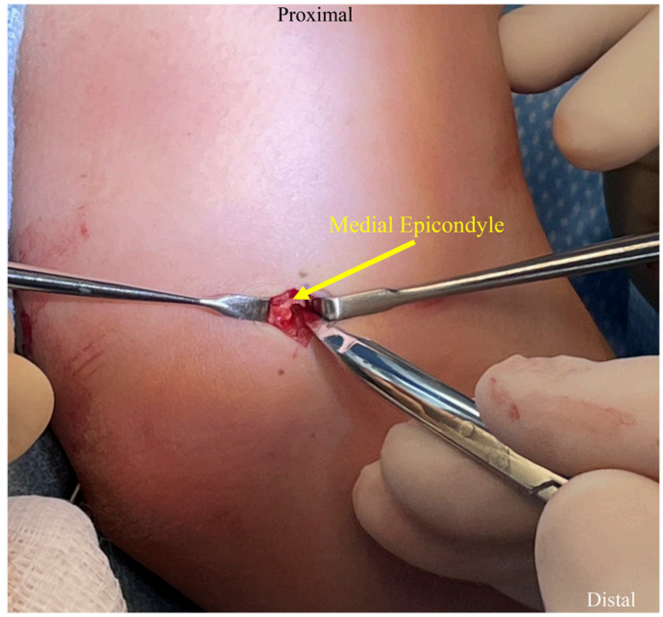

Fig. 2
Dissection is carefully taken down to the origin of the flexor-pronator mass on the medial epicondyle.

Materials and Methods

This study was approved by the Vanderbilt University Medical Center (VUMC) institutional review board (#171899).

Surgical Technique: Mini-Open Placement of the Medial Pin

The mini-open technique was first described by Green et al.[8] and Kocher et al.[24]; it involves dissection down to the medial epicondyle and placement of the medial pin under direct visualization.

Determining the Need for Medial Pin Placement

The decision to perform medial pin fixation (cross-pinning) is made intraoperatively after a demonstration of fracture instability following lateral-only pinning with 2 pins[25]. First described by Bauer et al.[26], the internal rotation stress test (IRST) is performed by rotating the arm internally while bracing the proximal part of the humerus to test the stability of the medial column after pin fixation[25-27]. If the IRST demonstrates medial column instability after the placement of 2 lateral pins, and assuming the fracture line does not run through the medial epicondyle, or too close to it to allow adequate purchase, medial pinning can be pursued as an alternative to a third lateral pin and as a preferred option to a fourth pin, lateral or medial, to achieve better medial column fixation[25].

Pre-Incision

Rates of ulnar nerve subluxation, although varied, have been reported to be as high as 27.5%[28]. Prior to placing the medial

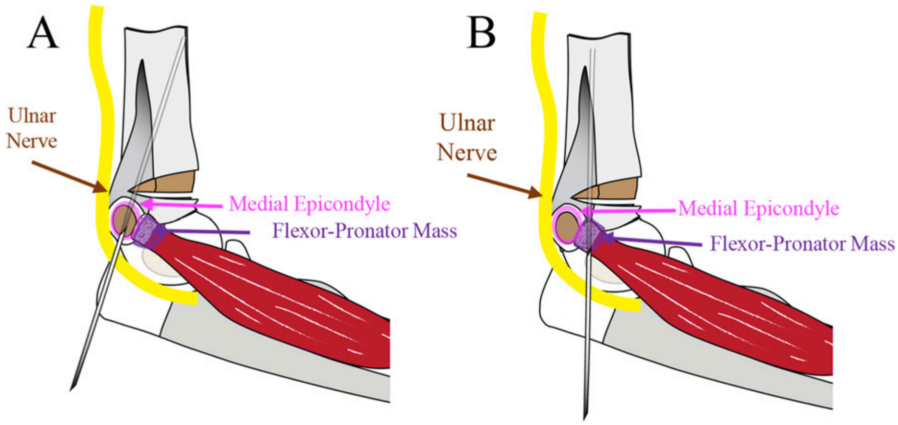

Fig. 3
The medial pin insertion with the medial epicondyle start point requires some retroversion of the pin trajectory (posterior to anterior trajectory) (A). With the flexor-pronator mass start point, the pin insertion aligns more coaxially with the humerus in the sagittal plane (B).

pin, it is important to be aware of this possibility. As ulnar nerve instability is usually bilateral[29] and it may not be possible or advisable to check for ulnar nerve instability in the injured extremity due to pain and swelling, an examination of the contralateral elbow may prove to be helpful in alerting the surgeon to the possibility of this finding in the injured extremity.

Surgical Approach to the Medial Epicondyle

The arm is placed in external rotation with the elbow flexed to 50° to 60° to provide comfortable access to the medial epicondyle and to reduce tension on the ulnar nerve. A small (approximately 1-cm) incision is made directly over or just anterior to the medial epicondyle (Fig. 1). Dissection is carefully taken down to the origin of the flexor-pronator mass on the medial epicondyle (Fig. 2). The key to safe insertion is identification of the medial epicondyle. The ulnar nerve does not have to be visualized if it is not subluxated or displaced. If the ulnar nerve is unstable, pinning should take place in less flexion (<45°). A blunt retractor can be used to protect the ulnar nerve during dissection and pin placement to ensure that it remains posterior to the medial epicondyle and clear of the insertion point and path of the pin.

Medial Pin Placement

Pin placement is performed directly through the medial epicondyle (Fig. 3-A) or slightly more anteriorly through the tendon of the flexor-pronator mass (Fig. 3-B). A Freer elevator, small, right-angled retractor, or drill sleeve can be used during pin placement to sweep soft tissues away and protect the ulnar nerve (Fig. 4). The desired starting point of the pin can be confirmed by palpating the borders of the medial epicondyle with a Freer elevator or the tip of the pin while watching it fluoroscopically, and the approach angle for the pin to optimally traverse the medial column can then be determined (Fig. 4).

IRST and Closure

The position of the pin is confirmed with static anteroposterior, lateral, and oblique fluoroscopic images. The stability of the reduction is then checked dynamically via the IRST, which is done by internally rotating the arm with the elbow flexed to 90° to stress the fracture and confirm maintenance of reduction and stability of the medial column on a true lateral fluoroscopic image[25]. Once stability is confirmed, the superficial wound is closed around the medial pin and all of the pins are bent over sterile felt and cut. The extremity is then immobilized in a cast or a splint with the elbow flexed to ≤80° (Fig. 5).

Case Series

Study Subject Selection

Using Current Procedural Terminology codes for the treatment of elbow fractures, we identified pediatric patients (newborn to 16 years of age) undergoing operative treatment for SCHFs at

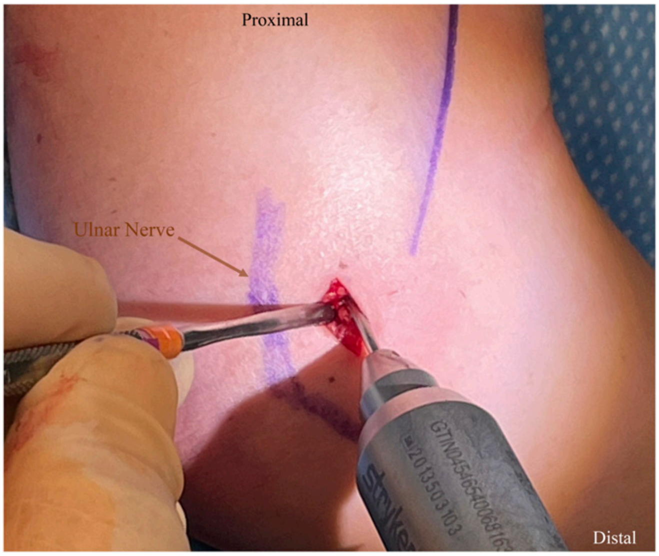

Fig. 4
A drill sleeve or Freer retractor can be used during pin placement to ensure the protection of soft tissues and the ulnar nerve.

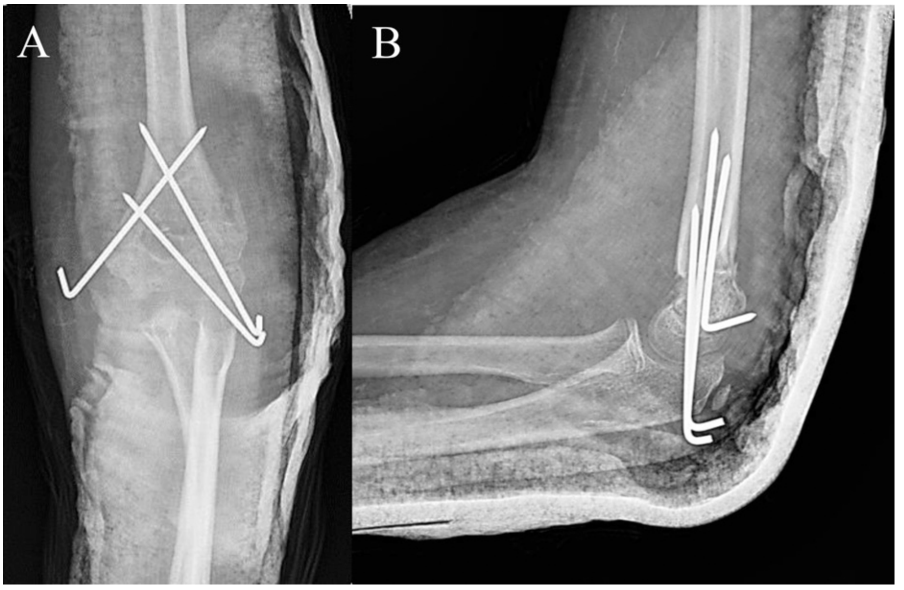

Fig. 5
Anteroposterior (A) and lateral (B) postoperative radiographs showing final reduction. Pins have been cut and bent and the splint was applied with the elbow flexed 80°.

Monroe Carell Jr. Children's Hospital at Vanderbilt between November 1, 2007, and October 31, 2017. A retrospective chart and imaging review was performed to identify a consecutive series of patients who underwent cross-pin fixation. Patients who were not treated with smooth pin fixation, underwent operative treatment at another hospital, had no postoperative follow-up (by means of at least 1 clinic visit), or died due to polytrauma were excluded. For patients meeting inclusion criteria, a retrospective review of the electronic medical record was used to gather data on injury characteristics, evaluation, treatment, long-term follow-up, and complications. De-identified data were stored and managed using REDCap electronic data capture tools hosted at the VUMC[30,31]. All patients undergoing medial pin placement (cross-pinning) were treated with the described mini-open technique. Outcomes included complications such as loss of fixation, osteonecrosis, malunion, nonunion, delayed union, pin track or deep-tissue infection, reoperation, and iatrogenic nerve injury. To provide additional insight into fracture severity, rates of concomitant nerve injury, indicators of fracture severity (such as skin tenting and open fractures)[32], and fracture type according to the Wilkins modification of the Gartland classification system[33] (as determined by the surgeon in the operative note and confirmed by radiographic review) were collected.

Indication for Medial Pin Placement

Prior to 2013, our institutional practice involved frequent use of cross-pinning across the spectrum of supracondylar fractures. In 2013, the IRST was implemented as an institutional practice and cross-pinning was only used in patients for whom the IRST indicated a need for additional fixation[27]. This updated decision model is the one used in the described technique.

Term Definitions

Iatrogenic nerve injury: The presence of any motor or sensory dysfunction in a specific nerve distribution not clearly documented preoperatively.

Loss of fixation: Any change in fracture alignment that required operative revision.

TABLE I Patient Demographic Characteristics

Sex*	
Female	315 (45.1%)
Male	382 (54.7%)
Unspecified	1 (0.1%)
Initial presentation location*	
Home institution	178 (25.5%)
Outside hospital	519 (74.4%)
Unspecified	1 (0.1%)
Age at injury *(yr)*	
Median	5.8
Minimum	0.8
Maximum	14.9
Standard deviation	2.5
Weight at injury *(kg)*	
Median	21.3
Minimum	8.3
Maximum	105.0
Standard deviation	9.6

*The values are given as the number of patients, with the percentage in parentheses.

TABLE II Fracture Type and Injury Severity*

Fracture type	
Gartland II	42 (6.0%)
Gartland III	538 (77.1%)
Gartland IV	22 (3.2%)
Flexion-type	35 (5.0%)
Metadiaphyseal junction	12 (1.7%)
T-type	12 (1.7%)
Unspecified	37 (5.3%)
Preoperative neurovascular injuries	
Median nerve	89 (12.8%)
Radial nerve	47 (6.7%)
Ulnar nerve	19 (2.7%)
Vascular injury	43 (6.2%)
Injury severity	
Skin tenting	32 (4.6%)
Open fracture	19 (2.7%)
Polytrauma	38 (5.4%)
Floating elbow	41 (5.9%)

*The values are given as the number of patients, with the percentage in parentheses.

Pin track infections: Local pin site erythema or purulence treated with oral antibiotics.

Deep infections: Infections requiring either intravenous antibiotics or operative irrigation and debridement.

Complications of union: Any variations in bone healing as documented on follow-up radiographs.

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Results

There were 1,625 patients who met inclusion criteria and were treated with smooth pin fixation by 1 of 7 pediatric orthopaedic surgeons at our institution during the study period: 927 patients with lateral pinning only and 698 patients with cross-pinning. Here we report the outcomes of a continuous series of the 698 patients treated with cross-pinning via the mini-open technique. The demographic information of the patients is detailed in Table I.

Fracture Severity and Complications

Fractures varied widely in severity. Gartland typing, rates of indicators of fracture severity, and rates of concomitant neurovascular injury in our case series are reported in Table II. Seventy-six fractures (10.9%) required open reduction. The rates of other complications included loss of fixation (9 patients [1.3%]), osteonecrosis (1 patient [0.1%]), and reoperation (22 patients [3.2%]) (Table III).

Iatrogenic Ulnar Nerve Injury

Three iatrogenic ulnar nerve injuries (0.43%), with varying clinical courses, were identified in the 698 patients treated with cross-pinning (Table IV). Patient 1 sustained a direct violation of the ulnar nerve while undergoing a revision pin placement after primary loss of fixation and was immediately symptomatic. As a result, patient 1 had both motor and sensory deficits in the ulnar nerve distribution and had mild symptoms at the last follow-up (21 weeks postoperatively). In patients 2 and 3, ulnar nerve symptoms were not diagnosed until their postoperative follow-up visits. Both patients 2 and 3 had complete resolution of ulnar nerve symptoms at their last follow-up, patient 2 at 8 weeks and patient 3 at 22 weeks, and neither required postoperative bracing, physical therapy, or occupational therapy.

Discussion

The rate of iatrogenic ulnar nerve injury in our large, single-technique case series of cross-pinning fixation for SCHF was approximately 10 times lower than generally accepted estimates.

Ulnar Nerve Injury: A Spectrum

There is little distinction made in the literature between direct violation of the ulnar nerve intraoperatively and delayed, often transient motor or sensory changes as a result of nerve compression by an indwelling pin. As such, it is difficult to assess the real clinical implications of iatrogenic ulnar nerve injury. In the vast majority of cases, even in studies with high rates of

TABLE III Rates of Complications and Indications for Reoperation*

Complication rates	
Compartment syndrome	2 (0.3%)
Loss of fixation	9 (1.3%)
Iatrogenic nerve injury	3 (0.4%)
Osteonecrosis	1 (0.1%)
Delayed union	3 (0.4%)
Malunion	2 (0.3%)
Pin track infection	18 (2.6%)
Deep infection	4 (0.6%)
Reoperation	22 (3.2%)
Indications for reoperation	
Loss of fixation	9 (40.9%)
Excision of buried pin	7 (31.8%)
Reinjury	2 (9.1%)
Compartment syndrome	2 (9.1%)
Irrigation and debridement of hematoma	1 (4.5%)
Malunion	1 (4.5%)
Total	22

*The values are given as the number of patients, with the percentage in parentheses.

TABLE IV Iatrogenic Ulnar Nerve Injuries

	Patient 1	Patient 2	Patient 3
Initial injury	Gartland IIIa (posteromedial) SCHF	Gartland IIIb (posterolateral) SCHF	Flexion-type SCHF
Preoperative examination	Posterior interosseous nerve palsy	Normal	Normal, but noted to be difficult due to patient's inability to cooperate
Ulnar nerve symptoms	Motor and sensory	Sensory only (pain with active motion of fifth digit)	Weakness with clawing in fourth and fifth digits
Presentation	Violation of nerve intraoperatively	3 weeks postoperatively	1 week postoperatively
Change in management	Immediate removal of violating pin	Routine removal of pin	Routine removal of pin
Length of deficits	Unknown	1 week	22 weeks
Full resolution of symptoms	No	Yes	Yes
Unresolved symptoms	Mild weakness and paresthesias in fifth digit	—	—
Length of follow-up	21 weeks	8 weeks	22 weeks
Physical therapy, occupational therapy, or bracing requirement	Yes	No	No

ulnar nerve injury, long-term follow-up data have suggested a full return of function in a matter of weeks to months[7], with the vast majority of patients with iatrogenic ulnar nerve injury having complete resolution of symptoms[10,12,16-18]. For example, Kalenderer et al. reported complete symptom resolution in their cohort of 25 patients with postoperative ulnar nerve symptoms at a mean of 2 months[34]. In our cohort, the 3 patients who sustained iatrogenic ulnar nerve injuries had a wide spectrum of symptoms and very different clinical courses. Patient 1's long-term motor and sensory deficits differed from patient 2's 1-week sensory irritation in the ulnar nerve distribution that resolved completely after routine pin removal. The latter is more similar to what is commonly seen, if not expected, in the placement of implants in other fracture types such as medial epicondylar fractures[35,36]. It may be useful to draw a clearer distinction in the literature between acute iatrogenic ulnar nerve injury and iatrogenic ulnar nerve impingement or irritation, because of their very different clinical consequences. For example, 2 of 3 patients had objective ulnar nerve deficits, and only 1 patient did not have complete resolution of those symptoms (Table IV). Thus, the rate of protracted ulnar nerve injury in this cohort was 0.14%.

The True Rates of Iatrogenic Ulnar Nerve Injury

In addition to the broad definition of iatrogenic ulnar nerve injury, the estimated rates of iatrogenic ulnar nerve injury draw on studies that used a broad range of techniques, including blind palpation and manipulation of the nerve[13-17,37,38], intraoperative nerve-locating electrodes[39], and ultrasound guidance[9]. The studies with some of the lowest rates of ulnar nerve injury used direct visualization via a mini-open technique[8,21,24,40-42]. However, almost all of these studies have been

TABLE V Comparison of Rates of Iatrogenic Nerve Injury Across Studies*

Study	Pin Placement Technique	Total Cases	Iatrogenic Nerve Injury† Ulnar Nerve	Median and Radial Nerves	All Nerves
Cross-pinning					
Current study	Mini-open	698	3 (0.43%)	0 (0.00%)	3 (0.43%)
Brauer[7] (2007)‡	Varied	1,171	40 (3.42%)	1 (0.09%)	41 (3.50%)
Slobogean[44] (2010)‡	Varied	4,436	161 (3.63%)	NR	NR
Dekker[12] (2016)‡	Varied	492	20 (4.07%)	NR	NR
Lateral pinning					
Brauer[7] (2007)‡	Varied	738	5 (0.68%)	9 (1.22%)	14 (1.90%)
Slobogean[44] (2010)‡	Varied	1,171	2 (0.17%)	NR	NR
Dekker[12] (2016)‡	Varied	666	2 (0.30%)	NR	NR

*NR = not reported. †The values are given as the number of patients, with the percentage in parentheses. ‡Indicates meta-analysis of smaller studies.

limited by small cohorts, leaving space for continued debate about the true incidence and clinical relevance of iatrogenic ulnar nerve palsy. This study provides meaningful insight into this gap in knowledge using a single technique throughout a large case series.

The Mini-Open Technique for Safe Medial Pin Placement

Using inclusive criteria for nerve injury, the rate of iatrogenic nerve injury while using the mini-open technique at our institution was 0.43%, nearly 10 times lower than rates previously reported in meta-analyses of cross-pinning. The rate in our series is also far lower than the all-nerve rate of iatrogenic injury in lateral pinning in the largest meta-analysis (Table V). Because of the size of our case series, these meta-analyses offer the only studies of comparable size. This case series (to our knowledge, the largest single-technique series) adds substantial support to the growing evidence that the mini-open technique is a safe method of cross-pinning[8,21,24,40-43]. The mini-open technique allows for direct visualization of the pin entry site, allowing for much more confident placement than blind placement with palpation. The scar from a mini-open incision is small (approximately 1 cm) and is often comparable with the scar that is frequently seen following pin insertion via a closed technique.

Beyond the Ulnar Nerve

Most literature on iatrogenic nerve injury in pediatric SCHFs focuses on cross-pinning and the ulnar nerve. However, iatrogenic nerve injury also occurs in lateral pinning. In a meta-analysis, Brauer et al. found the rate of iatrogenic nerve injury to be 1.9% in lateral pinning[7]. In that meta-analysis, the majority of nerve injuries in lateral pinning were to either the radial nerve or the median nerve (64.3%). More recent comparative analyses and decision models fail to account for the risk to these other nerves by only focusing on ulnar nerve injury rates[12,20,44], which represent a minority of iatrogenic injuries in lateral pinning. For example, in a decision model published in 2012, based on a rate of iatrogenic ulnar nerve injury of 3.4% for cross-pinning, Lee et al.[20] determined that the number needed to harm for cross-pinning compared with lateral pinning was 28. However, this number needed to harm took into account only ulnar nerve injury. Assuming that injury to any of the major nerves to the hand is an unacceptable outcome, these studies underestimated the risk of lateral pinning and may contribute to a notion that it is safer than it is. The rate of iatrogenic ulnar nerve injury reported in the present case series (0.43%) is more comparable with the rate of iatrogenic ulnar nerve injury alone in meta-analyses of lateral pinning (Table V).

Limitations

Our single-center case series is limited in its generalizability, and future external validation would strengthen our conclusions. Some variability in technique limited our study with respect to the exact placement site of the medial pin upon insertion via the mini-open technique. Due to insufficient documentation, which patients underwent medial epicondyle compared with flexor-pronator mass entry could not be determined for this study. Additionally, it is possible that mild ulnar nerve symptoms were not detected or recorded in the medical record. Finally, the retrospective nature of our data limited our ability to draw conclusions about complications such as malunion, as objective criteria were not able to be obtained and these diagnoses were only made clinically.

Conclusions

The mini-open technique described here is a safe method for placement of the median pin in pediatric SCHFs. In this study, the largest single-center case series of cross-pinning reported for SCHFs, the iatrogenic ulnar nerve injury rate was 0.43%, nearly 10 times lower than the generally accepted rate of approximately 3.4%. This was also far lower than estimated iatrogenic nerve injury rates for lateral pinning (1.9%). With only 1 of 698 patients having long-term nerve deficits, the risk of long-term injury was 0.1%. ■

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