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Internal Rotation Stress Test Reduces Cross-Pinning and Improves Outcomes in Displaced Pediatric Supracondylar Humeral Fractures

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Background: Stabilization of the medial column is vital in preventing the loss of fixation and malunion in displaced pediatric supracondylar humeral fractures (SCHFs). The preferred percutaneous pin configuration for medial column fixation remains controversial between medial pinning (cross-pinning) and additional lateral-based pinning. The intraoperative internal rotation stress test (IRST) has been proposed to reliably determine the optimal fixation strategy for each unique fracture. This study evaluated the impact of implementing the IRST on both the choice of pin configuration and institution-wide complications in pediatric patients treated operatively for SCHFs.

Methods: Pediatric patients undergoing percutaneous pinning for SCHFs between 2007 and 2017 at a single center were retrospectively reviewed. The IRST was made a universal institutional practice in 2013. Patients were divided into 2 groups for analysis: (1) patients who underwent treatment before the IRST was implemented in 2013 (the pre-IRST group), and (2) patients who were treated after the IRST was implemented in 2013 (the IRST group). Subgroup analysis was completed for patients in the IRST group who were treated with cross-pinning or 3 lateral-based pins.

Results: In this study, 820 patients in the pre-IRST group and 636 patients in the IRST group were included. After the IRST implementation, the rate of loss of fixation fell from 1.2% to 0% ($p = 0.003$), and the reoperation rate fell from 3.3% to 0.2% ($p < 0.001$). No cases resulted in a loss of fixation after the adoption of the IRST. The number of patients treated with cross-pinning decreased significantly from 53.2% to 31.6% ($p < 0.001$) after the IRST implementation, yet cross-pinning continued to be used for more severe fractures. Complication rates within the IRST group were not significantly different ($p > 0.05$) between cross-pinning and 3 lateral-based pins.

Conclusions: In the largest cohort reported on to date, to our knowledge, institutional implementation of the IRST resulted in a significant reduction in the use of cross-pinning. Although the usage of cross-pinning decreased, cross-pinning was still used frequently in the most severe fractures. The IRST use also resulted in significantly fewer complications such as loss of fixation after institution-wide implementation of the IRST for treating pediatric SCHFs.

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

Displaced pediatric supracondylar humeral fractures (SCHFs) have long been safely stabilized after reduction by percutaneous pinning with Kirschner wire or Steinmann pin transfixation[1-3]. The final pin construct must ensure the stability of both the lateral and medial columns of the distal part of the humerus[4]. It is common to begin percutaneous pin stabilization of displaced SCHFs with lateral-entry pins[5]. With this approach, it is more straightforward to stabilize the lateral column. In contrast, disagreement exists among treating physicians over the best way to stabilize the medial column between the 2 most popular options: the addition of a medial-based pin (cross-pinning) or the placement of additional lateral-based pin(s) (lateral pinning)[6,7] (see Appendix Supplemental Figure 1). Loss of reduction at the medial column is an impactful complication that can lead to the need for revision fixation and/or malunion with cubitus varus deformity[6,8]. Some evidence has suggested that cross-pinning is more biomechanically stable[9-11]. However, cross-pinning poses a greater risk of iatrogenic ulnar nerve injury due to

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medial pin placement[9]. Thus, surgeons treating SCHFs must identify which fractures have medial column instability and then choose the best pin configuration for stabilization, all while minimizing the risk of iatrogenic injury or loss of fixation[7].

Classification systems used for SCHFs, such as the Wilkins modification to the Gartland system[12,13], describe where the periosteum is disrupted and predict the stability of the medial column. For example, posterolaterally displaced (Gartland IIIB) fractures have disruption of the anteromedial periosteum and marked instability at the medial column compared with their more stable posteromedial (Gartland IIIA) counterparts, which have an intact anteromedial periosteum[14]. The practical utility of these classification systems in preoperative planning is often limited by their reliance on radiographic features. Radiographs are frequently unhelpful in distinguishing more unstable fracture types because of their inability to visualize the periosteum, the practical difficulty of obtaining adequate radiographs in distressed children, and recoil of the fracture fragment (when the resting position of a fracture does not always reflect the maximum displacement that occurs at the moment of injury). In light of these limitations, careful intraoperative assessment, in the form of the intraoperative internal rotation stress test (IRST), was initially proposed by Zenios et al.[7] as a solution to both identify fractures with medial column instability and determine the optimal pin configuration for each unique fracture based on objective criteria[15,16]. The IRST uses intraoperative stress imaging with fluoroscopy to assess the stability of the medial column after the placement of 2 initial lateral pins (see Appendix Supplemental Figure 2). If instability is observed, additional fixation can be obtained by replacing pins or adding additional pins in the form of a medial pin (cross-pinning) or a third lateral pin. The IRST is then repeated to verify the stability of the chosen construct[7,14].

Prior research on implementing the IRST has indicated improvement in assessing the stability of fixation intraoperatively and in radiographic outcomes in small case series[7,15]. Prior to 2013, our institutional practice involved frequent use of cross-pinning. In 2013, our institution initiated a change of practice to include IRST use in the surgical treatment of all displaced pediatric SCHFs. Coupled with the high volume of pediatric SCHFs cared for at our institution, this allowed us to evaluate the effectiveness of implementing the IRST in reducing long-term complications, such as loss of fixation; to measure the impact of the adoption of the IRST on pin configuration choice; and to compare outcomes between cross-pinning and lateral pinning in patients who undergo a failed initial intraoperative IRST, in the largest cohort analyzed to date, to our knowledge.

Materials and Methods

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

Subject Selection

Using our institution's Research Derivative database and Current Procedural Terminology (CPT) codes (24546, 24545, 24538, and 24586) for the treatment of elbow fractures, this study identified skeletally immature pediatric patients (birth to 16 years of age) undergoing closed or open reduction with smooth pin fixation for SCHFs at Monroe Carell Jr. Children's Hospital at Vanderbilt between November 1, 2007, and October 31, 2017. Patients who were not treated with smooth pin fixation, underwent operative treatment at an outside hospital, or died due to polytrauma were excluded. The electronic medical record was used to retrospectively gather data on injury characteristics, evaluation, treatment, long-term follow-up, and complications. Data were stored in a deidentified manner and were managed using REDCap electronic data capture tools hosted at Vanderbilt University Medical Center[17,18].

Patients were treated by 1 of 7 pediatric orthopaedic surgeons at our institution during the 10-year study period. Following fracture reduction and initial fixation, the IRST involved "internally rotating the shoulder to approximately 90 degrees while applying an internal rotation force across the fracture, rotating the forearm versus the humerus"[16] (see Appendix Supplemental Figure 2). A lateral fluoroscopic image is then taken to assess the stability of the pin configuration, with special attention to the medial column. If the medial column was grossly unstable on lateral fluoroscopic imaging (e.g., the distal fracture fragment can be seen translating posteriorly relative to the medial column) during the IRST (see Appendix Supplemental Figure 2), pins were reapplied or additional fixation was placed in the form of either a medial pin (cross-pinning) or additional (third) lateral pins. The IRST was incorporated as a change of practice by all pediatric orthopaedic surgeons at our institution in 2013. Given variations in the timing of adoption, 2013 was designated as a transitional year and was removed from the analysis (see Appendix Supplemental Table 1). Prior to 2013, the IRST either was not used or was inconsistently used by surgeons; patients treated during this period comprised the pre-IRST group. By the beginning of 2014, all pediatric orthopaedic surgeons at our institution were using the IRST consistently; patients treated in this time period were designated as the IRST group. The choice between cross-pinning and lateral pinning was determined by the attending surgeon based on clinical history, intraoperative IRST, and surgeon preference.

Term Definition

In terms of complications, loss of fixation was defined as any change in fracture alignment that required revision operation. Pin-track infections were defined by local pin site erythema or purulence treatable by oral antibiotics. Deep infections were defined as infections requiring either intravenous antibiotics or operative irrigation and debridement. Malunion was diagnosed clinically by the surgeon in follow-up clinic visits or if the fracture required reoperation for corrective osteotomies. Concomitant neurovascular injury, skin tenting, open fractures, and concomitant polytrauma were collected as markers of injury severity[19].

Statistical Analysis

Descriptive statistics were compiled for demographic characteristics and other study data, including the median, maximum and minimum, mean, and standard deviation where

TABLE I Patient Demographic Characteristics and Injury Severity

	Pre-IRST (N = 820)	Transition (N = 169)	Post-IRST (N = 636)
Sex*			
Female	392 (48%)	71 (42%)	311 (49%)
Male	428 (52%)	98 (58%)	325 (51%)
Age at injury *(yr)*			
Median	5.5	5.5	6.0
Minimum	0.3	1.0	1.0
Maximum	14.9	15.4	14.3
Standard deviation	2.6	2.4	2.4
Weight at injury *(kg)*			
Median	20.4	20.0	21.5
Mean	22.3	21.7	23.1
Minimum	6.5	9.1	9.2
Maximum	105.0	70.1	77.0
Initial presentation location*			
Study institution	273 (33%)	63 (37%)	192 (30%)
Outside hospital	547 (67%)	105 (62%)	442 (69%)
Not specified	0 (0%)	1 (1%)	2 (0.3%)
Markers of injury severity*			
Skin tenting	24 (3%)	6 (4%)	13 (2%)
Open fracture	11 (1%)	3 (2%)	13 (2%)
Neurovascular injury	130 (16%)	31 (18%)	102 (16%)
Polytrauma	41 (5%)	6 (4%)	27 (4%)

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

appropriate. Fisher exact tests and t tests with a Welch correction were applied to the different variables to compare between the IRST and pre-IRST groups. Variables compared between groups included initial injury characteristics, operative variables, and outcomes. For the patients in the IRST group, a subgroup analysis was completed between those who underwent cross-pinning and those who had a third lateral pin placed. All statistical calculations and the figure were generated with GraphPad Prism version 8.0.0 for Mac OS X (GraphPad Software).

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Results

Pre-IRST Compared with IRST

Of the 2,888 pediatric patients with SCHFs seen at our institution from November 2007 through October 2017, 1,625 patients underwent percutaneous pin fixation for SCHFs during the study period. There were 89 patients (5.5%) classified as undergoing an open reduction with smooth pin fixation, and the majority of these procedures were converted to an open reduction for vascular injury exploration or because the injury was an open fracture. Demographic information of the patient cohort is detailed in Table I. Markers of injury severity[19], such as soft-tissue injury (skin tenting and open fractures) and neurovascular injury, were not significantly different between cohorts (Table I). In this study, 820 patients were treated without the IRST (the pre-IRST group, treated from 2007 to 2012) and 636 patients were treated with the IRST (the IRST group, treated from 2014 to 2017). In 2013, the transition year, 169 patients were treated.

Before implementation of the IRST, 10 (1.2%) of 820 patients had a loss of fixation. After implementation of the IRST, the rate of loss of fixation ($p = 0.003$) and reoperation rate ($p < 0.001$) decreased significantly (Table II). No cases of loss of fixation were noted after the adoption of the IRST. There were 3 iatrogenic nerve injuries before the implementation of the IRST and 0 injuries after the implementation ($p = 0.262$). Rates of other complications, such as compartment syndrome, osteonecrosis, infection, and Volkmann contracture, were not found to be significantly different ($p > 0.05$) between the groups. The indications for reoperation are detailed in Table III.

Cross-Pinning Compared with 3 Lateral Pins

After the adoption of the IRST, the number of pins used per patient decreased significantly; there were a mean of 2.47 pins for the pre-IRST group and a mean of 2.36 pins for the IRST group ($p < 0.001$). Because the IRST is completed after the placement of 2 lateral pins, the addition of a third pin after

TABLE II Complications in the Pre-IRST Group and the IRST Group

Complication	Pre-IRST* (N = 820)	IRST* (N = 636)	P Value
Compartment syndrome	3 (0.4%)	0 (0.0%)	0.262
Loss of fixation	10 (1.2%)	0 (0.0%)	0.003
Osteonecrosis	1 (0.1%)	1 (0.2%)	0.999
Malunion	0 (0.0%)	0 (0.0%)	—
Pin-track infection	20 (2.4%)	8 (1.3%)	0.125
Deep infection	5 (0.6%)	3 (0.5%)	0.999
All-cause reoperation	27 (3.3%)	1 (0.2%)	<0.001
Volkmann contracture	0 (0.0%)	0 (0.0%)	—
Iatrogenic nerve injuries	3 (0.4%)	0 (0.0%)	0.262

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

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TABLE III Indications for Reoperation

Indication	Pre-IRST*	Post-IRST*
Loss of fixation	10	—
Buried pin excision	8	—
Reinjury	2	—
Compartment syndrome	2	—
Irrigation and debridement	4	1
Malunion	1	—
Total	27	1

*The values are given as the number of patients.

IRST implementation indicates IRST failure. A total of 274 such patients required the placement of an additional pin due to instability on the IRST. Of these, 201 patients were treated with cross-pinning, and 73 patients were treated with a third lateral-based pin. Complication rates were not significantly different between cross-pinning and 3 lateral-based pins ($p > 0.05$) (Table IV).

Pin Configuration Choice and Fracture Severity

After the change in practice to the use of the IRST, the proportion of fractures treated with cross-pinning fell significantly (53.2% for pre-IRST compared with 31.6% for IRST; $p < 0.001$) (Table V, Fig. 1). Both before and after the adoption of the IRST, fractures with a greater number of severity markers, such as open fractures, skin tenting, and neurovascular injury, were more likely to be treated with cross-pinning (Table V).

Discussion

In the largest cohort reported on to date, adoption of the IRST was associated with less frequent use of cross-pinning as well as a significant reduction in complication rates such as loss of fixation and reoperation. This large, retrospective cohort analysis demonstrates a clear reduction in the rate of loss of fixation associated with the implementation of the IRST for treating pediatric SCHFs.

The IRST Reduces Loss of Fixation

Our study presents strong evidence for the use of the IRST in treating displaced pediatric SCHFs. This assessment of the adequacy of fixation of the medial column was associated with a decreased loss of fixation and lower rates of all-cause reoperation. Intraoperative assessment of medial column stability appears to translate to better-quality fixation of the fracture. With regard to the reoperation rate, 1 possible explanation could be the significantly lower number of pins per patient used in the IRST group. In theory, this reduces the risk of pin complications such as infection and buried pins, which were common indications for reoperation in the pre-IRST group (Table III). We hypothesize that fewer pins are used with the IRST because the IRST reassures the surgeon of the adequacy of fixation, preventing the placement of additional pins that do not add to the stability of the construct.

Cross-Pinning Compared with Lateral Pinning: Objective Insight from the IRST

As a test of medial column instability, the IRST provides objective intraoperative data about the adequacy of any given pin construct. The previous practice at our institution was to cross-pin the majority of type-III SCHFs. This practice did not rely on objective criteria to determine the pin configuration. This placed us in a unique position to test the effect of implementing the IRST. An additional benefit of the implementation of the IRST seen in this study was the reduction in the use of cross-pinning for pediatric SCHFs. A large number of patients who likely would have been treated with cross-pinning before the IRST implementation were noted to have satisfactory fixation and had low complication rates with lateral pinning only, avoiding the increased risk of iatrogenic ulnar nerve injury[6,9].

However, in the years after IRST implementation, the number of patients who were treated with cross-pinning appeared to reach an equilibrium, suggesting that there is still a subset of fractures that require cross-pinning to obtain a satisfactory intraoperative IRST and long-term fixation. In both the pre-IRST and IRST time periods, cross-pinning was used in fractures with significantly more markers of instability (Table V). Although limited by our nonrandomized study design and far-from-conclusive evidence, these findings continue to provide insight into the ongoing discussion on preferred pin configuration. Because preoperative prediction of the stability of fractures is uncertain, it is important to use intraoperative assessment and the IRST to determine stability and inform pin configuration.

When the IRST Indicates the Need for More Fixation

In addition to demonstrating the value of the IRST, our data provided some insight on which pin configuration should be

TABLE IV Complications with Use of 3 Lateral Pins and Cross-Pinning

Complication	3 Lateral Pins* (N = 73)	Cross-Pinning* (N = 201)	P Value
Compartment syndrome	0 (0.0%)	0 (0.0%)	—
Loss of fixation	0 (0.0%)	0 (0.0%)	—
Osteonecrosis	0 (0.0%)	0 (0.0%)	—
Malunion	0 (0.0%)	0 (0.0%)	—
Pin-track infection	0 (0.0%)	4 (2.0%)	0.576
Deep infection	1 (1.4%)	1 (0.5%)	0.463
All-cause reoperation	1 (1.4%)	0 (0.0%)	0.266
Volkmann contracture	0 (0.0%)	0 (0.0%)	—

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

TABLE V Injury Severity of Fractures Treated with Cross-Pinning and Lateral Pinning Before and After the IRST*

	Cross-Pinning†	Lateral Pinning†	P Value
Pre-IRST (n = 820)	436 (53.2%)	384 (46.8%)	
Neurovascular injury	98 (22.5%)	32 (8.3%)	<0.001
Skin tenting	19 (4.4%)	5 (1.3%)	0.012
Open fracture	8 (1.8%)	3 (0.8%)	0.234
Polytrauma	21 (4.8%)	20 (5.2%)	0.873
IRST (n = 636)	201 (31.6%)	435 (68.4%)	
Neurovascular injury	56 (27.9%)	46 (10.6%)	<0.001
Skin tenting	9 (4.5%)	4 (0.9%)	0.006
Open fracture	8 (4.0%)	5 (1.1%)	0.031
Polytrauma	12 (6.0%)	15 (3.4%)	0.145

*The transition year data were excluded when comparing these methods. †The values are given as the number of patients, with the percentage in parentheses.

used if the intraoperative IRST indicates medial column instability. In this scenario, the replacement of initial pins, conversion to cross-pinning, or additional lateral pinning (third pin) may be pursued. The retrospective nature of our data limited our ability to include patients who simply required repositioning of lateral pins. However, we did compare outcomes between conversion to cross-pinning and additional (third) lateral pin placement. Although pin configuration was determined by the surgeon's choice, complication rates were not significantly different between the 2 constructs. This suggests that either our study was underpowered to detect a difference if one exists, or it was masked by a lack of randomization, given that more unstable fractures were treated with cross-pinning. Previous literature has been limited in its ability to answer this particular question, as the use of the IRST is often not clarified. Therefore, we are unable to conclude which is the preferred configuration. Regardless of the chosen construct, our evidence does suggest that the use of the IRST to verify the stability of either construct is associated with fewer complications, regardless of the configuration used.

Study Limitations

Our study was limited by several factors. The retrospective nature of this study limited the accuracy and completeness of some data and diagnoses. For example, height was not collected for all patients, limiting our ability to calculate body mass index for all patients. Some complications, such as malunion and osteonecrosis, were limited in their evaluation as objective criteria were not able to be collected and only clinical diagnosis could be used. Likewise, our retrospective cohort was subject to the limitation of surgeon choice in pinning strategy and was not randomized. Finally, the retrospective nature of this study precluded the evaluation of interobserver and intraobserver reliability when utilizing an IRST. As implementation was institution-wide, surgeons evaluating for loss of fixation were not blinded to the presence or absence of IRST use, creating the potential for observation and confirmation bias.

Although a notable strength, the length of our study period also presented some limitations. Some surgeons included in the study were not employed at our institution for the entire duration of the study. Countless small adjustments to practice over a 10-year period likely contributed to many potential confounding variables. Furthermore, the surgeons in the study no doubt benefited from the accumulation of experience over the 10-year course of the study. These limitations aside, our study provides strong evidence that institutional implementation of the IRST is associated with decreased complications.

Conclusions

In displaced SCHFs, obtaining medial column stability is a key to successful treatment. The use of an objective biomechanical test in the operating room (IRST) allows for the evaluation of the fixation of the medial column. Reassurance from the IRST may help surgeons to avoid unnecessary additional pins and their accompanying risks. When used in the operating room as an institutional practice, the rates of complications fell. Although implementing the IRST also significantly reduced the use of cross-pinning, the continued use of cross-pinning after the IRST implementation suggests that this technique is important for the most unstable fractures. Given the minimal risk of the IRST as an intervention, this large, retrospective cohort study provides strong support for implementation of the IRST in surgeons' operative algorithms for treating pediatric SCHFs.

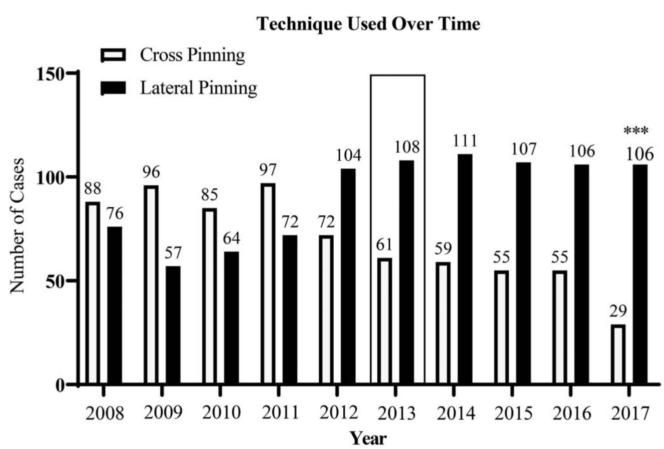

Fig. 1

Bar graph showing the techniques used over time. The box around 2013 designates it as the transition year. Data for 2007 were omitted because it was an incomplete year of data and had so few patients, so there is a discrepancy between the total number of patients in the text and tables (636) and in the figure (628). ***Indicates an incomplete year of data (through October 31, 2017).

Appendix

eA Supporting material provided by the authors is posted with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJSOA/A297). ■

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