Complications With Surgical Treatment of Pediatric Supracondylar Humerus Fractures: Does Surgeon Training Matter?

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Introduction: National trends reveal increased transfers to referral hospitals for surgical management of pediatric supracondylar humerus (SCH) fractures. This is partly because of the belief that pediatric orthopaedic surgeons (POs) deliver improved outcomes compared with nonpediatric orthopaedic surgeons (NPOs). We compared early outcomes of surgically treated SCH fractures between POs and NPOs at a single center where both groups manage these fractures.

Methods: Patients ages 3 to 10 undergoing surgery for SCH fractures from 2014 to 2020 were included. Patient demographics and perioperative details were recorded. Radiographs at surgery and short-term follow-up assessed reduction. Primary outcomes were major loss of reduction (MLOR) and iatrogenic nerve injury (INI). Complications were compared between PO-treated and NPO-treated cohorts.

Results: Three hundred and eleven fractures were reviewed. POs managed 132 cases, and NPOs managed 179 cases. Rate of MLOR was 1.5% among POs and 2.2% among NPOs ($P = 1$). Rate of INI was 0% among POs and 3.4% among NPOs ($P = 0.041$). All nerve palsies resolved postoperatively by mean 13.1 weeks. Rates of reoperation, infection, readmission, and open reduction were not significantly different. Operative times were decreased among POs (38.1 vs. 44.6 min; $P = 0.030$). Pin constructs were graded as higher quality in the PO group, with a higher mean pin spread ratio ($P = 0.029$), lower rate of "C" constructs (only 1 "column" engaged; $P = 0.010$) and less frequent crossed-pin technique ($P < 0.001$). Multivariate analysis revealed minimal positive associations only for operative time with MLOR (odds ratio = 1.021; $P = 0.005$) and INI (odds ratio = 1.048; $P = 0.009$).

Conclusions: Postsurgical outcomes between POs and NPOs were similar. Rates of MLOR were not different between groups, despite differences in pin constructs. The NPO group experienced a marginally higher rate of INI, though all injuries resolved. Pediatric subspecialty training is not a prerequisite for successfully treating SCH fractures, and overall value of orthopaedic care may be improved by decreasing transfers for these common injuries.

Level of Evidence: Level III—retrospective cohort study.

Key Words: supracondylar humerus fracture, training, major loss of reduction, iatrogenic nerve injury, complications, value of care

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Supracondylar humerus (SCH) fractures are the most common operative fracture encountered in children, representing 3% of all pediatric fractures.[1,2] Recent national trends reveal an increasing rate of transfers to pediatric tertiary referral centers for operative management.[2–5] While this trend is multifactorial, the belief that subspecialty-trained pediatric orthopaedic surgeons (POs) at referral centers will have improved patient outcomes and fewer complications compared with nonpediatric orthopaedic surgeons (NPOs) is somewhat responsible.[4,6] However, POs are lacking in some regions and families may be inconvenienced with transfers to tertiary care facilities.

Improving value in the delivery of orthopaedic care has emerged as a critical priority in the United States.[7,8] Value may be enhanced by optimizing outcomes and reducing costs through elimination of nonvalue added steps in care delivery.[8,9] One such opportunity for cost reduction within pediatric fracture care is decreasing unnecessary emergency department transfers, which average $4843 per transfer in the United States.[10]

Surgical treatment of SCH fractures has decreased the frequency of cubitus varus deformity from 58% to 3%,[11] and long-term functional outcomes remain excellent despite complications.[12–14] Major loss of reduction (MLOR) and iatrogenic nerve injury (INI) are some of the most feared complications of pinning SCH fractures,[15–17] with rates of MLOR ranging from 2.9% to 13.4% and rates of INI ranging from 2.9% to 3.9%.[15,17–20] Debate persists about whether complications and radiographic

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outcomes of SCH fractures differ between POs and NPOs.[5,21,22]

At our pediatric tertiary referral center, SCH fractures are regularly managed by both POs and NPOs on call. We hypothesize that postoperative outcomes, including MLOR and INI, would not vary significantly in patients undergoing surgery by POs compared with NPOs.

METHODS

A retrospective analysis of patients undergoing operative treatment of SCH fractures from January 2014 to May 2020 at a single tertiary care center where both POs and NPOs cover primary pediatric call was conducted. Patients were identified through Current Procedural Terminology (CPT) codes for SCH fractures undergoing operative management. Exclusion criteria consisted of children below 3 or above 10 years old, fractures with articular component, or lack of follow-up to fracture healing. The study was approved by the Institutional Review Board (IRB #16-1684).

Outcomes

Primary complications were MLOR and INI. MLOR was defined as >12 degrees change of Baumann's angle (BA) from intraoperative to follow-up imaging on anteroposterior view or loss of anterior humeral line (AHL) intersecting the ossification center of the capitellum on lateral radiographs at follow-up.[23,24] INI was included when the postoperative physical exam suggested nerve damage that was not present preoperatively. Secondary outcomes included quality of initial reduction (as defined by BA between 64 and 81 degrees and presence of AHL intersecting the capitellum), overall complications, pin characteristics, quality of fixation construct, need for open reduction, surgical time, overnight start time (defined as 7 PM to 7 AM), and length of stay.

Radiographic Review

Radiographs at surgery and short-term follow-up were analyzed to assess quality and maintenance of reduction. Collected data included: BA immediately postreduction and at follow-up, presence of AHL intersecting capitellum on lateral view immediately postreduction and at follow-up, pin spread distance and ratio (Fig. 1A),[26] pin fixation construct (Fig. 1B),[25] and use of lateral or cross pins. Inter-rater reliability between three independent reviewers, calculated from a subset of 5 cases, was high. The intraclass correlation coefficient was 0.926 [95% confidence interval (CI): 0.532-0.981] for BA and 0.831 (95% CI: 0.193-0.953) for pin spread ratio. There was total agreement between the measurements for both AHL and pin construct. Intrarater reliability, calculated from the same subset of cases, was also satisfactory. The mean difference in BA was 0.2 (95% CI: −0.8 to 1.2) and in pin spread ratio was 0.002 (95% CI: −0.015 to 0.019), both showing no significant difference.

Chart Review

Each case underwent chart and radiographic review by 1 of 3 independent data collectors. All data was deidentified, entered into a RedCAP database and secured per IRB protocol. Secondary, blinded review of charts and radiographs was performed by the senior author (fellowship-trained PO) for cases that were concerning for INI or MLOR. Cases that met the numerical criteria for MLOR were critically analyzed for evidence of true displacement between fracture fragments versus change in measurements attributable to differing XR views without clear evidence of reduction loss. These cases because of change in XR view were not counted in the MLOR outcome.

Call Structure

The details of timing and treatment for SCH fractures at study institution are important to consider. The emergent night and weekend call at our institution is covered by both POs and NPOs, in a roughly 1:4 ratio, with residents assisting during cases. During this study period, NPOs managed an average of 29.4 operative SCH fractures yearly, compared with 23.3 by POs, and displaced fractures (Gartland type 2+ and flexion-type injuries) were indicated for surgery. Reductions were not routinely attempted in the emergency department. Timing of surgery was at the discretion of the on-call surgeon. Generally, cases deemed to be urgent/emergent receive surgery shortly after presentation (often overnight), while nonemergent cases are admitted with plans to be transferred to the care of a PO the next day. When a PO was not immediately available for next day care (ie, over the weekend), the original on-call surgeon would often surgically manage nonemergent cases.

Statistical Analysis

A priori power analysis was conducted to ensure the ability to detect a clinically significant rate difference of 10% for both major outcomes and determined a sample size of 130 in each group was needed to detect this difference. This rate was chosen based on precedent, though thresholds could be debated. Authors of a prior randomized-controlled trial on pin entry location believed 10% loss of reduction rate to be significant enough to warrant changing practice.[24] We determined that a 10% difference in INI rates would similarly warrant change. Bivariate analysis was conducted comparing primary and secondary outcomes between POs and NPOs. A logistic regression model that included multiple independent variables was conducted to study the adjusted association in the multivariate analysis. A stepwise variable selection procedure was carried out to ensure a robust estimate.

RESULTS

A total of 426 patients with SCH fractures were identified. One hundred and nineteen patients were omitted from the analysis because of lack of follow-up, excluded fracture type, unknown surgeon not associated with our practice, or age below 3 or above 10. Of the 307 patients included in the study, 4 experienced an additional SCH

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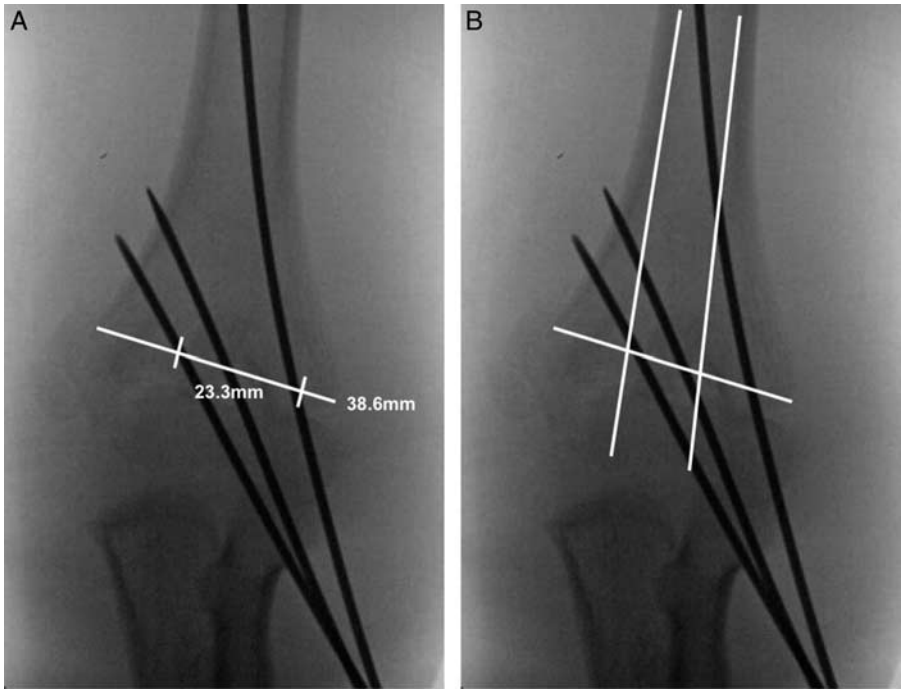

FIGURE 1. Measurements on radiographic review. A, Pin spread ratio measurement intraoperative anteroposterior view measuring coronal width of the humerus at the level of the fracture (38.6 mm) and pin spread distance (23.3 mm) to calculate pin spread ratio of 0.60 (23.3 mm/38.6 mm). B, Pin fixation construct measurement. The quality of pin constructs was graded using a rating of A, B, or C.[9,25] Pins with bicortical fixation and maximal pin spread at the level of the fracture on the anteroposterior view (1 pin in the medial third of the humerus and 1 pin in the lateral third of the humerus at the level of the fracture) received an A grade. Constructs with pins in the central third of the humerus and 1 in either the lateral or the medial third of the humerus on the anteroposterior view received a B grade. Constructs with pins only in the lateral or central third of the humerus received a C grade. This case received a B grade with pins in the central third of the humerus and 1 in the lateral third of the humerus on anteroposterior view.

fracture not related to the initial injury, resulting in a total of 311 operatively treated fractures (Fig. 2). There were 103 Gartland type 2, 170 Gartland type 3, 28 Gartland type 4, and 10 flexion-type fractures, distributed among POs and NPOs. Sample characteristics included an average age of 6.09 years and 49.8% male (Table 1). Six POs performed 132 (42.4%) cases, and 18 NPOs performed 179 (57.6%) cases (individual surgeon case load depicted in Fig. 3).

Six cases of MLOR were identified through radiographic analysis (Fig. 4) and deemed true on expert secondary review. Six cases of true INI were identified and confirmed by expert secondary review (4 ulnar and 2 median nerve injuries). Bivariate analysis of the primary outcomes revealed a 1.5% rate of MLOR among the POs and 2.2% among NPOs ($P=1$), as depicted in Table 2. The rate of INI was 0% among the POs and 3.4% among the NPOs ($P=0.041$). All nerve palsies resolved during follow-up (mean 13.1 wk, range: 3.6 to 36.4 wk).

Bivariate analysis of secondary outcomes is also included in Table 2 (complications) and Table 3 (operative details). Rates of infection, reoperation, readmission, and combined complications were similar between PO and NPO groups. Of the 7 patients experiencing infection, 2 required surgical irrigation and debridement. Mean operative times were decreased with POs compared with NPOs (38.1 vs. 44.6 min; $P=0.0297$), though rates of open reduction were similar (3.8% vs. 4.5%; $P=1$). The NPO group took significantly more cases to the odds ratio (OR) overnight (21.2%) compared with the PO group (3.8%) ($P<0.001$).

Radiographic analysis revealed less frequent cross-pin technique among the PO group (9.8% vs. 32.4%; $P<0.001$). POs had a higher mean pin spread ratio than NPOs (0.51 vs. 0.47; $P=0.0288$), a higher rate of optimal "A" grade pin constructs (26.5% vs. 17.3%; $P=0.01$), and a lower rate of suboptimal "C" grade pin constructs (1.5% vs. 7.8%; $P=0.01$). POs had a small proportion of inadequate initial reduction as defined by radiographic measurements (1.52% vs. 0%; $P=0.099$), though there was not further LOR in these cases.

Secondary analysis revealed independent variables associated with MLOR. MLOR was more common in Gartland type 3 and Gartland type 4/flexion-type injuries ($P=0.016$). Cross-pin technique also had a positive association with MLOR ($P=0.026$). Multivariate analysis for independent variables associated with MLOR or INI revealed only a minimal positive association with length of procedure (OR: 1.021; 95% CI: 1.006-1.036; $P=0.005$ for MLOR, and OR: 1.048; 95% CI: 1.012-1.085; $P=0.009$ for INI). No other independent variables were significantly associated with the primary outcomes.

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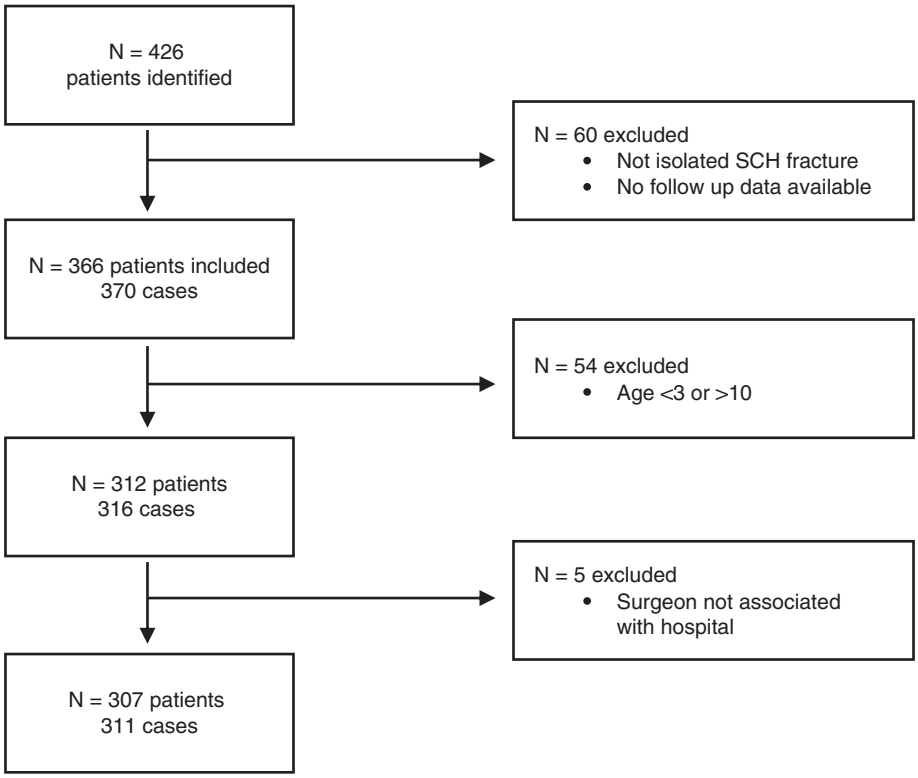

FIGURE 2. Flow diagram of patients and SCH fracture cases included in the study. SCH indicates supracondylar humerus.

DISCUSSION

SCH fractures are the most common surgically treated fracture in children and are regularly transferred to tertiary referral hospitals for management by POs.[2–5] Despite many studies focusing on postoperative outcomes among these patients, the need for treatment by POs over NPOs is debatable.[5,21,22] Limiting unnecessary transfers is an opportunity for cost reduction, lessening burden on families and limiting delay in care, provided patient outcomes are equivalent between POs and NPOs.[8–10,22] To our knowledge, this is the largest series comparing operatively treated pediatric SCH fractures outcomes between POs and NPOs since 2008, more accurately reflecting current trends and modern training in a more subspecialized area.

TABLE 1. Sample Characteristics (N = 311 Cases)

Characteristic	POs (N = 132), N (%)	NPOs (N = 179), N (%)	Total (N = 311), N (%)	*P*
Mean age (y)	5.92	6.21	6.09	0.141
Sex: male	63 (47.7)	92 (51.4)	155 (49.8)	0.567
Gartland type 2	52 (39.4)	51 (28.5)	103 (33.1)	0.00384*
Gartland type 3	73 (55.3)	97 (54.2)	170 (54.7)	
Gartland type 4**	4 (3.0)	24 (13.4)	28 (9.0)	
Flexion type	3 (2.3)	7 (3.9)	10 (3.2)	

*Statistically significant using $\alpha = 0.05$.
**Classified in the operating room as a fracture with complete periosteal disruption and instability in both flexion and extension.
NPO indicates nonpediatric orthopaedist; PO, pediatric orthopaedist.

In 2008, Farley et al[5] retrospectively evaluated 444 SCH fractures managed by POs and NPOs at an academic tertiary referral center found no significant difference in overall complication rates (16.8% PO vs. 22.7% NPO). Similar to our findings, NPOs did have a higher percentage of patients taken to the OR on an emergent basis (62.4% vs. 32.5%), but repinning rates and INI rates were similar between groups.[5] Data used in this study predates ours by ~15 years, with the results perhaps being less applicable in the modern era of subspecialty-focused orthopaedics.

Ralles et al[6] used the American Board of Orthopedic Surgeons (ABOS) Part II database to compare outcomes of 9169 SCH injuries treated by POs and NPOs who were 2 years into practice. While they found POs had a significantly lower rate of complication than NPOs (7% vs. 8.4%),[6] this difference was ~1.4%, leading the authors to question strength of evidence to support transfers to a tertiary center. This study also found that POs performed open reduction more often than NPOs, contrary to our study's findings. It should be noted that this data was self-reported and the limitations of the database limit accuracy of MLOR or INI rates. Nevertheless, this suggests that most orthopaedic surgeons graduating in the United States in recent years are adequately prepared to manage SCH fractures regardless of subspecialty training.

In 2015, Dodds et al[22] compared clinical and radiographic outcomes of 90 NPO-managed and PO-managed SCH fractures. NPOs had longer mean operative times, higher rates of open reduction, and were more

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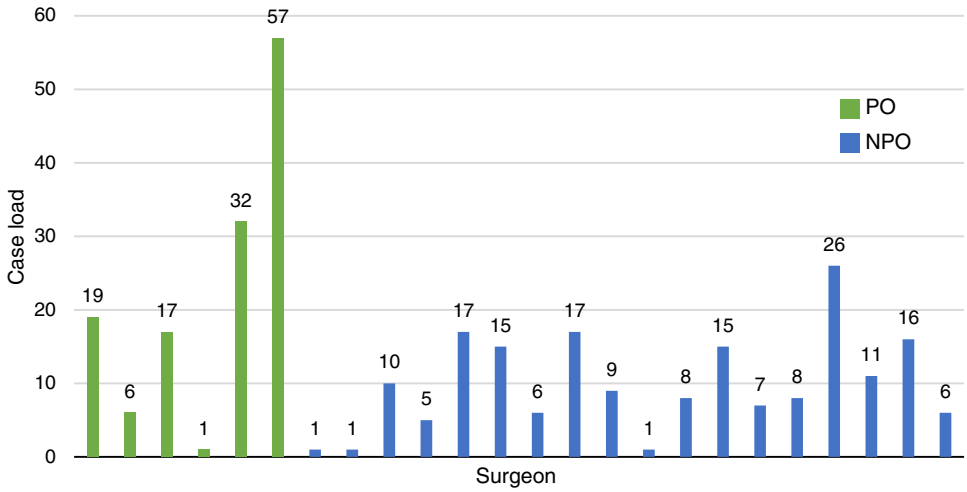

FIGURE 3. Case load among 6 POs and 18 NPOs during the study period. NPO indicates nonpediatric orthopaedist; PO, pediatric orthopaedist.

likely to have inadequate fracture fixation (43.5% vs. 14.7%) as defined by Skaggs and colleagues.[22,23] Despite this, clinical outcomes were similar between groups. Rates of INI were higher in this study than previous reports in the literature (9.1% NPO vs 12.3% PO),[15,18,20] and sample size was considerably smaller than aforementioned studies.

In the present study, many findings of the prior studies are reinforced. The rate of MLOR was not different between groups, despite differences in pin constructs. MLOR was more common in complex fracture patterns, as expected. The NPO group experienced a statistically higher rate of INI (3.4%) but did not meet our prespecified a priori complication rate difference of 10%. Though cross-pin technique was higher among NPOs, which is thought to increase likelihood of INI, multivariate analysis did not show an association with INI (ie, the cases with INI were not necessarily cases who received crossed-pins). Furthermore, 2/6 INI cases involved the median nerve, which cannot be explained simply by the addition of a medial pin. Fortunately, all injuries resolved

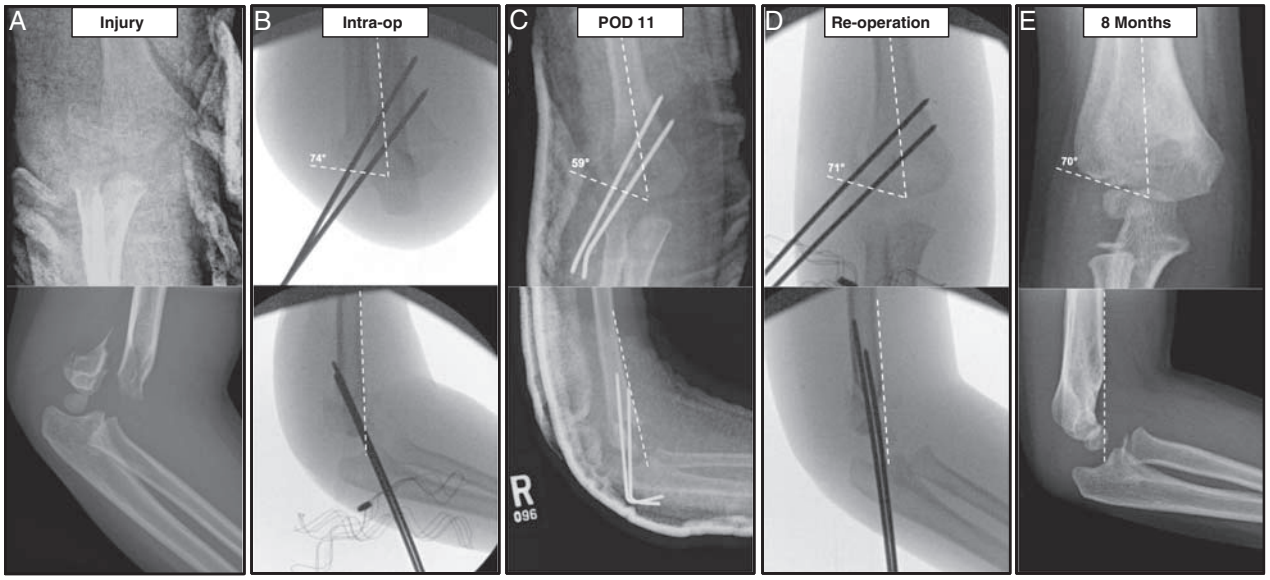

FIGURE 4. Example of MLOR diagnosed by radiographic measurements. A, Anteroposterior and lateral radiographs of 3-year-old right hand dominant male revealing right Gartland type 3 SCH fracture with posterolateral displacement. B, Reduction and fixation. BA measured 74 degrees intraoperatively; AHL intersects capitellum. C, POD 11 radiographs noted distal fragment rotation. BA measured 59 degrees; capitellum posterior to AHL consistent with MLOR. D, Repeat reduction and pinning (POD 13). BA measured 71 degrees; AHL once again intersects capitellum. E, Final follow-up (8 mo). BA measures 70 degrees. AHL intersects capitellum confirming maintenance of reduction. AHL indicates anterior humeral line; AP, anteroposterior; BA, Baumann's angle; MLOR, major loss of reduction; POD, postoperative day; SCH, supracondylar humerus.

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TABLE 2. Results of Bivariate Analysis Comparing Complications Between POs and NPOs

Outcome	POs (N = 132), N (%)	NPOs (N = 179), N (%)	Total (N = 311), N (%)	*P*
MLOR	2 (1.5)	4 (2.2)	6 (1.9)	1
INI	0	6 (3.4)	6 (1.9)	0.0405*
Infection	1 (0.8)	6 (3.4)	7 (2.3)	0.245
Reoperation	1 (0.8)	2 (1.1)	3 (1.0)	1
Readmission	0	2 (1.1)	2 (0.6)	0.51
Combined complications	2 (1.5)	9 (5.0)	11 (3.5)	0.125

*Statistically significant using $\alpha = 0.05$.
INI indicates iatrogenic nerve injury; MLOR, major loss of reduction; NPO, nonpediatric orthopaedist; PO, pediatric orthopaedist.

by an average of 13 weeks. The 3.4% rate of INI seen in patients treated by NPOs are comparable to historic standards (2.9% to 3.9%),[15,18,20] and clinical significance is debatable.

Surgeon training was not a significant factor associated with primary outcomes in the multivariate analysis, indicating that major complications are multifactorial. On the basis of our call structure, more complex or high-energy fractures deemed to be urgent/emergent appear to be more commonly treated by NPO surgeons in this cohort. This occurs because there are more NPOs than POs in our practice and they are statistically more likely to be on call any given evening. If a complex injury comes in overnight, it is therefore more likely to be treated by an NPO; whereas the lower-energy fractures that are safe to defer until morning will typically be treated by a PO the next day. Multivariate analysis suggests only OR time was associated with INI, likely serving as a proxy for fracture complexity. Other early postsurgical outcomes between POs and NPOs were similar in this study. Complication rates of infection, reoperation, and readmission showed no difference between groups and were universally low, similar to historic standards.[16,27,28]

While our study did not demonstrate clinically important differences in the main clinical outcomes (based on our a priori criteria), we believe the study revealed several other significant findings. POs used cross-pin technique less than their NPO counterparts, favoring more exclusive lateral entry, which may reflect current trends in pediatric subspecialty training. Radiographic analysis showed superior technical constructs in the PO group compared with the NPO group, including more grade A constructs and a higher mean pin spread ratio—though this did not result in a difference in reduction outcomes. These findings are consistent with the current literature, which shows no association between pin spread ratio and loss of fixation above a ratio of 0.33.[26,29]

There are several limitations of this study. SCH fractures typically have short-term follow-up, ranging from 2 to 8 weeks, so long-term outcomes could not be assessed. Given the nature of a retrospective cohort study, data was based on outcomes available in notes found in the electronic health record. In addition, radiographic outcomes were determined by 3 independent reviewers, introducing the possibility for measurement bias and interobserver variability. Cases that possibly had major complications of interest were reviewed secondarily to ensure major outcomes were true MLOR or INI. While the distribution of injuries treated by POs vs. NPOs are different in this sample as a result of the call setup, introducing possibility for confounding factors affecting complications between groups, other demographic and institutional factors are similar between the 2 groups to still allow a meaningful comparison. Because the frequency of primary outcomes was low in this study, our multivariate analysis was limited. Lastly, there needs to be a distinction between the NPOs in this study, who self-select to treat these injuries by taking pediatric call, versus a general orthopaedic surgeon who perhaps has not treated this injury since training.

Our findings support the assertion that pediatric subspecialty training is not a prerequisite for safely and successfully treating SCH fractures. NPOs had a statistically increased rate of INI (3.4%) but did not meet our predefined threshold for clinical significance and is consistent with historical rates. POs may more closely adhere to current surgical principles such as lateral entry and increased pin spread principles, but it did not lead to an

TABLE 3. Results of Bivariate Analysis Comparing Operative Details Between POs and NPOs

Outcome	POs (N = 132)	NPOs (N = 179)	Total (N = 311)	*P*
Operative time (min), mean (SD)	38.1 (20.0)	44.6 (31.9)	41.9 (27.6)	0.0297*
Hospital stay (d), mean (SD)	0.917 (0.537)	0.917 (0.444)	0.917 (0.482)	0.988
Overnight start time, N (%)	5 (3.8)	38 (21.2)	43 (13.8)	< 0.001*
Open reduction, N (%)	5 (3.8)	8 (4.5)	13 (4.2)	1
Medial pin used, N (%)	13 (9.8)	58 (32.4)	71 (22.8)	< 0.001*
Pin diameter (mm), mean (SD)	1.74 (0.218)	1.74 (0.217)	1.74 (0.217)	0.891
Number of pins, mean (SD)	2.52 (0.545)	2.75 (0.605)	2.66 (0.591)	< 0.001*
Pin spread ratio, mean (SD)	0.510 (0.147)	0.472 (0.151)	0.488 (0.151)	0.0288*
Pin construct grade A, N (%)	35 (26.5)	31 (17.3)	66 (21.2)	0.00977*
Pin construct grade B, N (%)	95 (72.0)	134 (74.9)	229 (73.6)	
Pin construct grade C, N (%)	2 (1.5)	14 (7.8)	16 (5.1)	

*Statistically significant using $\alpha = 0.05$.
NPO indicates nonpediatric orthopaedist; PO, pediatric orthopaedist.

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important difference in clinical outcomes. These findings should not be generalized to say that any orthopaedist can treat SCH fractures, as many transfers may be warranted. However, NPOs with the proper training and experience should feel empowered to treat these injuries if they feel comfortable with injury management. The authors believe that transferring patients for the sole purpose of operative management by a PO may be unnecessary and decreases overall value of orthopaedic care by incorporating non-value added steps in care delivery.

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