Journal of the Pediatric Orthopaedic Society of North America 7 (2024) 100035

Contents lists available at ScienceDirect

Journal of the Pediatric Orthopaedic Society of North America

journal homepage: www.jposna.com

Original Research

Use of paralytic agents during the operative treatment of type III supracondylar humerus fractures in children: A single-center investigation and survey of Pediatric Orthopaedic Society of North America members

John A. Schlechter, DO[1,2,3,*], Loren C. Tholcke, DO[1,2], Trenton G. Lum, DO[2], Evelyn S. Thomas, DO[2,4], Bryn R. Gornick, BS[2,3], Gian C. Ignacio, BS[5], Jessica C. McMichael, MD[2,3]

[1] *Riverside University Health System – Medical Center, Department of Orthopaedic Surgery, Moreno Valley, CA, USA*
[2] *CHOC Children's Hospital, Orange, CA, USA*
[3] *Pediatric Orthopaedic Specialists of Orange County, Orange, CA, USA*
[4] *Kettering Health Dayton, Dayton, OH, USA*
[5] *The Warren Alpert Medical School of Brown University, Providence, RI, USA*

ARTICLE INFO

Keywords:
Supracondylar fracture
Neuromuscular blockade
Reduction
Paralytics
Children

ABSTRACT

Background: Paralytic agents are occasionally used during the surgical treatment of type III (OTA 13A2) supracondylar humerus fractures (SCHFx) in children depending on surgeon preference. Paralytic agents create a neuromuscular blockade and therefore may potentially help with ease of fracture reduction. Controversy regarding the use of a paralytic agent as an adjunct to anesthesia exists due to potential associated adverse drug reactions, including prolonged paralysis, cardiovascular effects, or electrolyte abnormalities.

The purpose of this study was to investigate intraoperative paralytic use in pediatric type III SCHFx and to report survey responses of members of the Pediatric Orthopaedic Society of North America (POSNA) on paralytic use in SCHFx management.

Methods: A retrospective chart review identified 319 type III SCHFx treated at our institution (January 2016–May 2019). Patients were assigned to 3 groups: group 1, surgical treatment without a paralytic agent (n = 240); group 2, treatment with rocuronium (n = 43); group 3, treatment with succinylcholine (n = 36). POSNA members were surveyed regarding paralytic use intraoperatively for type III SCHFx (November–December 2021) on paralytic use frequency, request for paralytics, reversal agent use, average time to surgery after injury and/or presentation, effect of time to surgery after injury and/or presentation on when to use a paralytic, annual number of SCHFx surgeries performed, awareness of paralytic complications, and years of surgeon experience. Statistical analysis was performed.

Results: Average patient age was 5.2 ± 2.2 years. Group 2 had significant increases in anesthesia duration, surgical duration, fluoroscopic time, and radiation exposure compared to group 1. Group 2 had a higher conversion rate to open reduction than other groups. No statistically significant difference was found among groups in terms of sex, body mass index (BMI), laterality, radiographic measurements, or rates of open procedures or complications. Survey results indicated 32% (24/76) routinely use paralytics during closed reduction maneuvers; 71% (17/24) request administering paralytics at the beginning/before the case; and 33% (8/24) use paralytics in all type III SCHFx.

Conclusions: Surgeons at our center reported paralytic use for closed reduction in 25% of patients; similarly, one-third of POSNA survey respondents reported paralytic use during operative management. Although paralytic agents are used during the treatment of supracondylar humerus fractures in children this study was unable to demonstrate an association of advantageous outcomes, such as shorter surgical times. Routine

* Corresponding author: Pediatric Orthopaedic Specialists of Orange County, 1310 W Stewart Dr #508, Orange, CA 92868, USA.
E-mail address: info@youthsportsortho.com (J.A. Schlechter).

https://doi.org/10.1016/j.jposna.2024.100035
Received 27 March 2024; Accepted 27 March 2024
Available online 4 April 2024

paralytic use to facilitate closed reduction of supracondylar humerus fractures in children warrants further study.

Key Concepts:

(1) Paralytic agents may be utilized in pediatric supracondylar humerus fracture (SCHFx) surgeries, but their efficacy remains controversial due to associated adverse reactions.
(2) Administration of rocuronium during surgery was associated with prolonged anesthesia and surgical durations, as well as increased fluoroscopic time and radiation exposure, suggesting potential drawbacks to its use.
(3) Despite common use, the study found no significant correlation between paralytic agent administration and beneficial outcomes such as shorter surgical times.
(4) Survey responses revealed varying practices among orthopaedic surgeons regarding paralytic agent use during closed reduction maneuvers for SCHFx.
(5) Understanding variations in paralytic agent use among orthopaedic surgeons underscores the importance of future research to guide clinical decision-making.
(6) The study highlights the need for standardized protocols and evidence-based practices in the use of paralytic agents for pediatric SCHFx.
(7) The findings underscore the need for further research to establish the efficacy and safety of routine paralytic use in pediatric SCHFx surgeries and inform standardized protocols.

Level of Evidence: III, Retrospective chart review; Therapeutic study

Introduction

Supracondylar humerus fractures (SCHFx) are one of the most common pediatric elbow fractures found in children less than 7 years of age, with 60.3 to 177 emergency department visits per 100,000 children annually [1–3]. SCHFx are often classified using the Wilkins modification of the Gartland classification: type I, non-displaced fracture; type II, displaced fracture with intact posterior cortex and variable angulation/rotation; type III, displaced fracture without intact cortex [4,5]. It is estimated that 96–98% of SCHFx are extension type, and 26% of those are Gartland type III variants [6]. Standard treatment of type III SCHFx is an attempted closed reduction or open reduction when a closed reduction is not acceptable nor achievable, followed by percutaneous smooth metal pin fixation for stability [7–11].

Continued debates at our weekly fracture conference revealed that some surgeons at the study institution were using paralytic agents to facilitate closed reduction when they treated patients with type III SCHFx under the assumption that closed reduction would be achieved more seamlessly. Typically, paralytic agents are used as an inductive agent at the discretion of the anesthesiologist or as a neuromuscular blockade at the request of the treating surgeon to assist closed reduction maneuvers. There is a paucity of literature focused on routinely utilizing a paralytic agent during the surgical treatment of type III SCHFx to ease closed reduction and if its use affects surgery in quantifiable measures.

The purpose of this study was 2-fold: first, to investigate the effect of intraoperative paralytic administration on the surgical treatment of type III SCHFx in children at our institution, and second, to survey members of the Pediatric Orthopaedic Society of North America (POSNA) regarding their use of paralytic agents in the management of these fractures.

We hypothesized that the administration of paralytic agents during surgical treatment of type III SCHFx in children would result in less complex procedures. We anticipated that quantifiable measures, such as shorter surgical and anesthesia durations, reduced fluoroscopic exposure and duration, lower rates of conversion to open reduction, and fewer postoperative complications, would be observed in patients who received paralytic agents compared to those who did not.

Additionally, we hypothesized that the rate of paralytic agent utilization for closed reduction maneuvers in type III SCHFx surgeries, as reported by survey respondents, would be comparable to the rate observed among pediatric orthopaedic surgeons at our institution.

Materials and methods

Retrospective chart review

A retrospective Institutional Review Board (IRB)-approved review of type III SCHFx treated from January 01, 2016, to May 22, 2019, at the study institution was performed. No outside funding was received for this work. The medical records of 534 children were identified using International Classification of Diseases Tenth Revision (ICD-10) codes S42.411 or S42.412 and Current Procedural Terminology (CPT) codes 24538 (Percutaneous skeletal fixation of supracondylar or transcondylar humeral fracture, with or without intercondylar extension) and 24545 (Open treatment of humeral supracondylar or transcondylar fracture, including internal fixation, when performed; without intercondylar extension). Inclusion criteria consisted of Gartland type III SCHFx initially treated surgically with attempted closed reduction with percutaneous pinning (CRPP), patient age 1–10 years, adequate radiographs at the time of surgery to demonstrate a type III SCHFx pattern, and follow-up to monitor changes in radiographic union, Baumann's angle, and lateral humerocapitellar angle. Children less than 1 year of age or older than 10 years were excluded due to the increased complexity of pediatric supracondylar fracture patterns with increasing age [12,13]. Additional criteria for exclusion were flexion-type injury pattern, incomplete anesthesia record, missing fluoroscopic information, and loss of follow-up until radiographic union.

Inpatient notes, operative notes (including anesthesia and nursing notes), and clinic notes were reviewed. Three groups of children were established: group 1, treated surgically without use of a paralytic agent; group 2, treated with rocuronium as the paralytic agent; group 3, treated with succinylcholine as the paralytic agent. All children were treated by 1 of 5 orthopaedic surgeons, 4 of whom were pediatric fellowship trained; one was a general orthopaedic surgeon with experience treating pediatric fractures.

Data were collected on age, sex, body mass index, laterality, anesthesia duration (time inductive agent was introduced to time patient extubated), surgery duration (time of procedure start defined as first fracture reduction attempt to procedure conclusion, defined as completion of application of immobilization cast or splint), injury to operating time, emergency room to operating room time, identity of the attending orthopaedic surgeon, conversion to open treatment, fluoroscopy time, fluoroscopic radiation exposure, pre-operative and post-operative complications, and differences of the variables among the 5 surgeons performing the cases.

Times from injury and emergency room presentation to start of operation were recorded to evaluate any effect prolongation to surgery may have had on reduction difficulty, and thus, requiring the use, type, or higher doses of paralytic agents.

Pre-operative fracture-associated injuries included nerve palsy, vascular compromise (sluggish capillary refill of greater than 3 seconds or absent radial pulse), or combined nerve and vascular compromise. Post-operative complications included the same criteria as pre-operative complications as well as loss of functional range of motion, defined

as any arc of passive motion less than 30°−130° by week 12 of follow-up [14], and fracture displacement, both of which were used as measures of fracture reduction quality.

Post-operative skeletal alignment was measured on radiographs using post-operative Baumann and lateral humerocapitellar angles [15]. All radiographic measurements were performed by one orthopaedic surgery resident physician, who was in their fourth year of post-graduate training.

Survey administered to the Pediatric Orthopaedic Society of North America

An IRB-approved survey about the use of paralytic agents during closed reduction of type III SCHFx was administered to POSNA members in October–December 2021 via e-mail link to Research Electronic Data Capture (REDCap). Inclusion criteria for the survey were orthopaedic surgeons who were members of POSNA and provided their informed consent to participate in the survey. Incomplete surveys were excluded from analysis. Survey questions were designed to assess the percentage of surgeons who used paralytic agents to ease closed reduction maneuvers for type III SCHFx during surgery and the details of their use, such as frequency of paralytic agent use, request for specific paralytic agent(s), use of a reversal agent, effect of time to surgery on the decision to use a paralytic agent, time to surgery after injury and/or presentation, number of operative SCHFx performed per year, awareness of complications after use of a paralytic agent, and years of surgeon experience.

Statistical analysis

Data was analyzed by an independent statistician. Descriptive statistics were performed. Analysis of variance (ANOVA), Kruskal-Wallis, Mann-Whitney, Yuen-Welch, Bonferroni and Chi-square tests were performed to compare the above-mentioned groups and metrics. Post-hoc comparisons were performed for significant main effects. Continuous variables were analyzed and reported as mean ± standard deviation. Assumptions of normality and homogeneity of variances were evaluated prior to the use of parametric and nonparametric statistics. Analyses were performed using SPSS vs 25 (SPSS Statistics for Windows, IBM Corp., Armonk, NY) and JASP 0.16.0 (jasp-stats.org), with alpha set at $P < .05$ to declare significance.

Results

Retrospective chart review

A total of 319 children who met the study's inclusion criteria were identified during the retrospective chart review. There were 240 children in group 1 (no paralytic agent), 43 in group 2 (rocuronium) and 36 in group 3 (succinylcholine). Twenty-five percent of our study cohort received a paralytic agent.

Overall, the average age of children with an extension type III Gartland SCHFx was 5.2 ± 2.2 years (range, 1–10 years). The children in the rocuronium group were significantly older than those in the no-paralytic agent group (6.4 ± 2.2 years vs 5.0 ± 2.2 years, $P < .001$). Mean age in the rocuronium group was greater than that in the succinylcholine group (6.4 ± 2.2 years vs 5.4 ± 2.3 years, $P = .242$).

The rocuronium group received an average rocuronium dose of 0.43 ± 0.16 mg/kg (range, 0.20–1.00); the succinylcholine group received an average succinylcholine dose of 1.18 ± 0.48 mg/kg (range, 0.28–2.69). No children in the rocuronium group required a second dose of the paralytic agent.

Time from presentation in the emergency room to the start of the operation was shorter for those in the rocuronium group, compared to those who received succinylcholine or no paralytic agent (6.2 vs 6.4 and 8.2 hours, respectively, $P = .007$).

Statistical significance was noted in the surgical duration among the 3 groups ($P = .016$). Surgical duration was longer for children in the rocuronium group compared to those who received no paralytic agent (30 vs 23 minutes, $P = .013$). Surgical duration was longer for children who received succinylcholine (24 minutes) compared to those who received no paralytic agent ($P = .36$). No significant difference was observed between surgical duration for children who received rocuronium vs. succinylcholine ($P = 1$).

Children who received either paralytic agent had increased fluoroscopy time, compared to those who did not (no paralytic, 29.9 seconds; rocuronium, 48.5 seconds; succinylcholine, 33.2 seconds; $P < .001$). The rocuronium group had a statistically significant increase in fluoroscopy time compared to the no-paralytic agent group ($P < .001$), but no statistical difference was found between the rocuronium and succinylcholine groups ($P = .474$).

Statistically significant radiation exposure was found among the 3 groups ($P < .001$). Radiation exposure was higher in the rocuronium vs no paralytic agent groups (1.20 vs 0.63 mGy, $P < .001$), but there was no significant difference between the no-paralytic agent group and the succinylcholine group (0.67 mGy, $P = .378$). There was no difference in radiation exposure between the rocuronium and succinylcholine groups ($P = .139$).

Anesthesia duration among the 3 groups was statistically significant ($P = .003$). The rocuronium group had the longest anesthesia duration (67 minutes) among the 3 groups; this duration was significantly longer than in the no-paralytic agent group (55 minutes) ($P < .001$). There was no statistically significant difference in anesthesia duration between the no-paralytic agent group and succinylcholine group (57 minutes) ($P = .132$). No statistical significance was noted between the rocuronium and succinylcholine groups ($P = .307$).

There was no significant difference between groups for time from injury to the operating room ($P = .15$), sex ($P = .63$), body mass index (BMI) ($P = .72$), injury laterality ($P = .29$), or post-operative radiographic measurements (Baumann's and lateral humerocapitellar angle at approximately the 12-week mark ($P = .117$ and $P = .436$, respectively). There were no significant differences in post-operative outcomes among the orthopaedic surgeons who performed the procedure, and no anesthesia-related complications in any of the 319 study participants.

There was no statistically significant difference between the no-paralytic agent group and either rocuronium or succinylcholine groups noted regarding pre-operative ($P = .85$) and post-operative ($P = .64$) complications. Regarding preoperative complications, 10 children were noted to have anterior interosseous nerve (AIN) palsy, 4 had posterior interosseous nerve (PIN) palsy, 8 had sluggish capillary refill > 3 seconds or absent radial pulse, and 2 had combined vascular/nerve palsies. Only one patient who had vascular compromise required open reduction; this patient had no post-operative complications. Postoperatively, 8 additional children were found to have AIN palsy; the total number of children with isolated AIN palsy was thus 18 (5.6%). Three children were found to have PIN palsy postoperatively; the total number of children with isolated PIN palsy was 7 (2.2%). Return of function was achieved in all patients with AIN or PIN palsy. One patient developed a valgus deformity with malrotation after fixation. The comparative analysis for all 3 groups is depicted in Table 1.

When comparing groups with paralytic use vs no paralytic use (Table 2), no statistical significance was found between groups regarding performing an open reduction ($P = .909$), preoperative complications ($P = .379$), and postoperative complications ($P = .228$). Statistical significance between paralytic agent use and no paralytic agent use was found for anesthesia duration ($P < .001$), surgical duration ($P = .006$), fluoroscopic duration ($P < .001$), and radiation exposure ($P < .001$).

Statistical significance for paralytic agent use (49.0%, 29.4%, 23.7%, 20.9%, and 1.7% of cases) was found among the 5 attending surgeons ($P < .001$). Overall, rocuronium was used in 13.3% of cases, succinylcholine in 12.7% of cases, and no paralytic agents in 74% of cases. The indication for paralytic agent use and/or specific paralytic

Table 1
Comparative analysis among treatment groups.

	Overall	No paralytics	Rocuronium	Succinyl-choline	*P*-value
No. of patients	319	240 (75.2%)	43 (13.5%)	36 (11.3%)	–
Female %	53%	53%	58%	47%	.63
Age (years) mean ± SD	5.2 ± 2.2	5.0 ± 2.2	6.4 ± 2.1	5.4 ± 2.3	< .001
BMI mean ± SD	18.6 ± 15.9	18.7 ± 17.2	19.7 ± 13.4	16.6 ± 2.9	.72
Left-sided injury % (vs right)	64%	66%	54%	61%	.29
Anesthesia duration (minutes) median [Range]	57 [30-171]	55 [30-145]	67 [37-171]	57 [37–91]	.003
Surgery duration (min) median [Range]	24 [6-121]	23 [6-121]	30 [13–113]	24 [11–59]	.016
Injury → OR (hours) Median [Range]	8.3 [5.5-13.8]	9.2 [6.4-14.1]	7.7 [4.7-11.8]	5.8 [3.9-11.9]	.15
ED → OR (hours) median [Range]	7.5 [5.2-12.7]	8.2 [5.6-13.2]	6.2 [4.3-11.0]	6.4 [4.7-12.3]	.007
No. of Open reduction	8 (2.5%)	6 (2.5%)	2 (4.7%)	0 (0%)	.43
No. of Preop Complication	24 (9%)	17 (8%)	4 (11%)	3 (9%)	.85
No. of Postop Complication	47 (15%)	33 (14%)	8 (20%)	6 (17%)	.64
Fluoroscopy time (seconds) mean ± SD	32.8 ± 28.4	29.9 ± 27.3	48.5 ± 33.1	33.2 ± 23.6	< .001
Radiation exposure (mGy) mean ± SD	0.71 ± 0.80	0.63 ± 0.74	1.20 ± 1.00	0.67 ± 0.66	< .001
Bauman angle mean ± SD	73.5 ± 5.1	72.9 ± 5.5	75.6 ± 3.6	75.1 ± 2.3	.117
Lateral humerocapitellar angle mean ± SD	41.8 ± 8.3	41.3 ± 7.8	41.7 ± 9.1	44.8 ± 11.1	.436

P-value ≤ .05 statistically significant.

agent use was not recorded. Three of the surgeons had been practicing for 15–20 years (paralytic agent use: 49.0%, 29.4%, 23.7%) and 2 surgeons for 25–30 years (paralytic agent use: 20.9%, 1.7%). Surgical duration among the 5 surgeons was statistically significant ($P < .001$). Further analysis demonstrated the surgical duration for surgeon 4 had a statistically significant difference compared to the other 4 surgeons ($P < .01$) Table 3.

Survey administered to Pediatric Orthopaedic Society of North America

Seventy-six pediatric orthopaedic surgeons agreed to participate in the POSNA survey. Twenty-four surgeons (32%) said they usually use paralytic agents to ease the closed reduction of type III SCHFx while 52 surgeons (68%) said they do not utilize paralytic agents for type III SCHFx. Of the 24 surgeons who use paralytic agents, only 1 requested a specific paralytic agent (succinylcholine); none of the surgeons were aware of post-paralytic agent–or post-reversal agent-related complications. A radiographic image of a type III SCHFx was shown to the 24 surgeons to understand their preference for a paralytic agent during closed reduction of this fracture: 23 surgeons said they would use a paralytic agent while 1 surgeon said the decision to use a paralytic agent would be left to the discretion of the anesthesiologist (Fig. 1). Table 4 further demonstrates details of the use of paralytic agents during closed reduction of type III SCHFx by the 24 surgeons who use paralytic agents routinely.

Of the 17/24 surgeons who used paralytic agents routinely and requested medication administration at the beginning/before the case, 47% used paralytic agents in all cases while 35% used it in most cases. Seventy-one percent (12/17) of those who use paralytics at the beginning/before the case reported paralytic agent use does not depend on time to surgery after injury and/or presentation.

Seven surgeons said paralytic agent use was dependent on the time of surgery after injury and/or presentation; 0, 2, 4, and 1 surgeon operated emergently, same day, next day, and within 2–3 days, respectively.

Thirty-eight percent of those who use paralytic agents routinely (9/24) had been practicing for < 10 years while the second highest group who use paralytic agents routinely (6/24, 25%) had been practicing for > 20 years. Five surgeons (5/24) who use paralytic agents had been practicing for 10–15 years; 4 surgeons (4/24) who use paralytic agents had been practicing for 15–20 years. Among those practicing < 10 years and using paralytic agents routinely, 78% used paralytic agents at the beginning/before the case; 33% use paralytic agents in all cases vs 44% in most cases. Among those practicing > 20 years and using paralytic agents routinely, 33% use paralytic agents in all cases vs 67% in most cases. Thirty-three out of 76 orthopaedic surgeons did not ever request paralytic agents for type III SCHFx because they did not find its use necessary during closed reduction. One surgeon noted that he preferred open reduction if the fracture did not reduce within 3 attempts.

Discussion

Supracondylar humerus fractures are one of the most common fractures in the pediatric elbow [2] and account for two-thirds of all pediatric elbow injury hospitalizations [16,17] with attempted closed

Table 2
Comparative analysis between no paralytics vs paralytics groups.

	No paralytics	Paralytics	*P*-value
No. of patients	240 (75.2%)	79 (24.8%)	
Female %	53%	49%	.574
Age (years) mean ± SD	5.0 ± 2.2	5.9 ± 2.2	.001
BMI mean ± SD	18.7 ± 17.2	18.2 ± 9.9	.278
Left-sided injury % (vs right)	66%	55%	.041
Anesthesia duration (minutes) median [Range]	55 [30-145]	60 [37-171]	< .001
Surgery duration (minutes) median [Range]	23 [6-121]	23 [11-113]	.006
Injury → OR (hours) Median [Range]	9.2 [6.4-14.1]	7.6 [3.4-96]	.026
ED → OR (hours) median [Range]	8.2 [5.6-13.2]	6.5 [1.8-22.8]	< .001
No. of Open reduction	6 (2.5%)	2 (2.5%)	.909
No. of Preop Complication	17 (8%)	7 (9%)	.379
No. of Postop Complication	33 (14%)	14 (18%)	.228
Fluoroscopy time (sec) mean ± SD	29.9 ± 27.3	45.2 ± 34.4	< .001
Radiation exposure (mGy) mean ± SD	0.63 ± 0.74	1.05 ± 1.01	< .001
Bauman angle mean ± SD	72.9 ± 5.5	74.9 ± 3.6	.092
Lateral humerocapitellar angle mean ± SD	41.3 ± 7.8	43.0 ± 10.2	.833

Table 3
Comparative analysis among the 5 orthopaedic surgeons.

Surgeon	Years of experience	Number of cases with paralytic agent use/Total cases performed	Surgical duration (minutes)
1	15-20	14/59	17.8 ± 5.2
2*	25-30	1/57	25.9 ± 18.1
3	25-30	14/67	20.0 ± 8.9
4	15-20	25/85	33.8 ± 15.9
5	15-20	25/51	22.4 ± 12.0

* Did not complete a pediatric orthopaedic surgery fellowship.

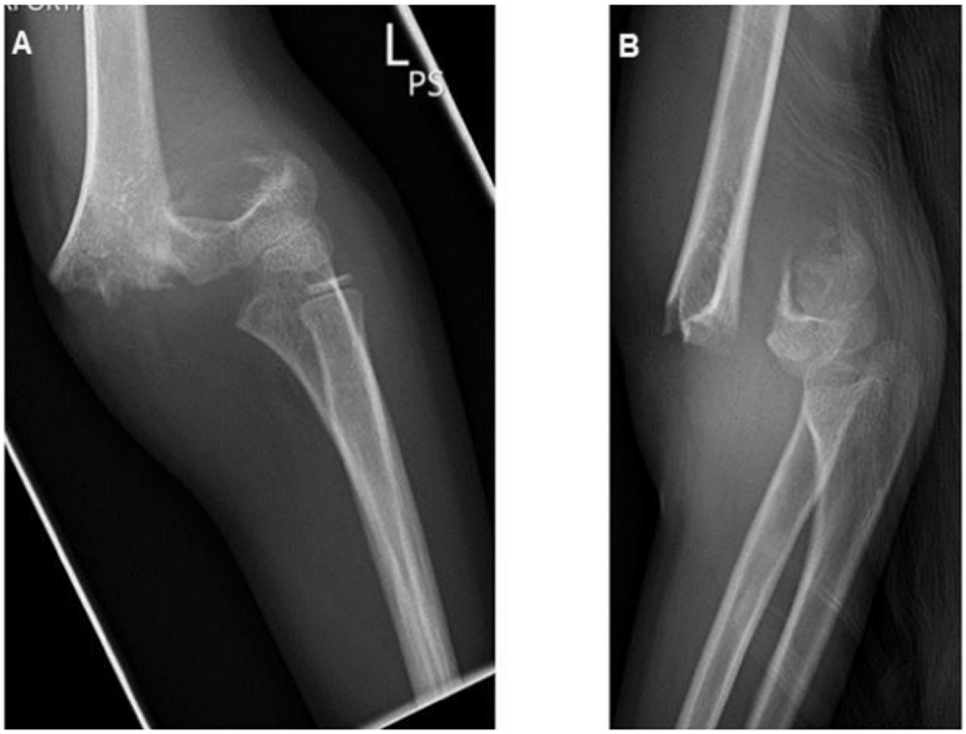

Figure 1. Pre-operative radiographs demonstrating a Gartland type III supracondylar humerus fracture. (A) Anteroposterior radiograph. (B) Lateral radiograph.

reduction and percutaneous pinning as the standard of care for type III SCHFx [18]. Goals for surgical treatment of SCHFx are to restore alignment typically by closed reduction methods and utilize techniques that would decrease the need for conversion to an open procedure that may lead to more cases with increased time to union, increase in wound dehiscence, and worse Flynn functional results [15]. Much of the available literature speaks to using anesthesia and analgesics effectively for pediatric fracture reductions as reducing the awareness and pain felt by the patient will induce some relaxation [19-21]. However, occasionally, a paralytic agent is used by some surgeons to provide a neuromuscular blockade to relax the muscles to ease the closed reduction maneuver of a type III SCHFx. Theoretically, the subsequent result of the ease of closed reduction maneuvers would decrease surgical time, fluoroscopic time, radiation exposure, and the need to convert to an open procedure. Typically when a paralytic is requested by a treating surgeon at our institution, the request is made prior to anesthesia induction as the choice of airway management may be affected (endotracheal intubation versus laryngeal mask airway in the setting of paralytic agent administration). Thus, paralytic agents in our study were likely to be used based on anticipated difficulty with reduction maneuvers rather than reduction difficulty experienced during the procedure.

Although the reason for using paralytic agents - whether it was for the ease of closed reduction or surgeon preference - was not recorded, our study did not demonstrate an advantageous effect of paralytic agent use on the variables studied. Therefore, we reject our hypothesis that children who received a paralytic agent would have a shorter anesthesia duration, shorter surgical duration, shorter fluoroscopy time, decreased radiation exposure, increased use with pre-operative fracture-associated injuries, and lower rates of conversion to an open reduction when compared to those children that underwent treatment without the use of a paralytic agent.

Interestingly, patients treated perioperatively with rocuronium did have a statistically significant longer anesthesia duration, increased fluoroscopic time, and increased radiation exposure compared to the succinylcholine and no-paralytic agent groups. Surgical duration was significantly longer in the rocuronium and succinylcholine groups when the 3 groups were assessed among each other; the rocuronium and succinylcholine groups also had surgery performed sooner than the no-paralytic group. This may signify that the paralytic groups had more difficult reductions compared to the no-paralytic group. The conversion rate from closed to open reduction was found to be 2.5% overall, which is similar to that reported in other studies [22,23]. Although not statistically significantly different, patients without any administered paralytic agent had a conversion treatment rate of 2.5% (6/240) while the rocuronium group had a rate of 4.7% (2/43). This is likely due to the increased difficulty encountered during closed reduction maneuvers. Similar results between the succinylcholine group and no-paralytic agent group may have occurred due to the short duration of action of approximately 4–6 minutes of succinylcholine, making it a less effective paralytic agent compared to rocuronium for difficult and lengthy reductions [24].

Table 4
Pediatric Orthopaedic Society of North America (POSNA) survey results.

When paralytic agent is requested	
Beginning/Before case	17 (71%)
During case when fracture is too difficult to reduce without muscle relaxation	7 (29%)
Frequency for request of use of a paralytic agent	
All the time	8 (33%)
Most cases	10 (42%)
Some cases	6 (25%)
If request use of a specific paralytic agent	
Yes	1 (4%)
No	23 (96%)
If aware of use of reversal agent	
Yes	4 (17%)
No	20 (83%)
If time to surgery after injury and/or presentation affects decision to use a paralytic agent	
Yes	8 (33%)
No	16 (67%)
Average time to surgery after presentation of uncomplicated type III SCHFx	
Emergent	2 (9%)
Same day	7 (30%)
Next day	13 (57%)
Within 2-3 days	1 (4%)
Number of SCHFx treated operatively per year	
0-25	5 (21%)
25-50	16 (67%)
50-75	3 (12%)

No anesthetic complications were documented for any of the 319 children included in this study. Despite any documented anesthetic complications, paralytic and paralytic reversal medications have reported risks. Succinylcholine has had rare reports of acute rhabdomyolysis with hyperkalemia followed by ventricular dysrhythmias, cardiac arrest, and even death in apparently healthy children who were subsequently found to have an undiagnosed skeletal muscle myopathy [25]. Rocuronium has documented reports of adverse reactions including anaphylaxis, malignant hyperthermia, cardiac arrhythmias, and prolonged paralysis requiring a reversal agent [26,27]. If reversal is needed, sugammadex is typically used, which can be costly and has inherent risks including but not limited to anaphylaxis, marked bradycardia, and the need for respiratory function monitoring. The safety and effectiveness of sugammadex has not been established in children less than 17 years of age [28].

When comparing the 5 surgeons included in this study, there was wide range of paralytic agent use among the surgeons although there were similar years of experience. Interestingly, the surgeons with 15–20 years of experience had longer surgical durations compared to the surgeons practicing for 25–30 years. This may indicate a difference in training between the generations of surgeons. One surgeon with 15–20 years of experience was found to be an outlier and had a statistically significant increased surgery duration compared to the other 4. However, this surgeon did perform more surgical cases for type III SCHFx which increases the likelihood of more difficult cases. The difficulty of the cases was not recorded for any of the surgeons.

Our institutional rate of 25% administration of a paralytic agent during the treatment of type III SCHFx in children, which was similar to that of the POSNA survey results in which a third of surgeons requested paralytic agents for reduction of type III SCHFx. This poses the question: why do two-thirds of orthopaedic surgeons not use paralytic agents or deem it unnecessary in the setting of closed reductions for type III SCHFx? Of the 24 surgeons who usually request paralytic agents, only 29% of surgeons requested paralytic agent administration intraoperatively due to the difficulty of the closed reduction compared to other respondents administering paralytic agents before surgical incision. Also, nearly half of the survey responders who requested paralytics before the start of the case use them in all their cases. Future studies are warranted to determine if paralytic agents are necessary without having attempted closed reduction of the fracture and knowing the actual difficulty of the reduction. The high percentage of those using paralytic agents who had been in practice for < 10 years and > 20 years indicate that factors other than experience may dictate the routine use of paralytic agents when reducing type III SCHFx, such as orthopaedic surgical training or institutional biases and cultures.

Strengths of our study include a large cohort of children treated by orthopaedic surgeons at a large metropolitan children's hospital, which is an American College of Surgeons level I trauma and regional tertiary referral center. Study limitations include no clear specification as to why a specific paralytic agent was chosen and by whom. Indications for use of a paralytic agent include difficulty in reducing a posteromedial or posterolateral type III SCHFx, suspicion of a type IV supracondylar humerus fracture, the size of the patient regarding a muscular or lean arm or attending and/or resident experience. The patients receiving paralytic agents had shorter times from the emergency department to the operating room, longer operative times, longer anesthesia durations, and greater fluoroscopic use compared to those who did not receive paralytic agents. These factors appear to be reflective of the anticipated severity or complexity of the cases, rather than the outcomes of paralytic agent use itself. That said, multiple of these indications could have played a role in the decision of the surgeon and/or anesthesiologist in a given case. The use of paralytic agents did not have a significantly higher complication rate, though need for a higher power study could have contributed to this.

The selection bias in this study arises from the non-random assignment of patients to receive paralytic agents versus no paralytic agents. The decision to use paralytic agents was likely influenced by the surgeon's perception of the anticipated difficulty of the fracture reduction, rather than being randomly assigned. This means the paralytic agent groups were selectively enriched with more complex or challenging fracture cases, as evidenced by their shorter times to the operating room from the emergency department.

This selection bias can significantly impact the validity and interpretation of the study results. The longer operative times, increased fluoroscopy use, and other factors observed in the paralytic agent groups may not be due to the paralytic agents themselves, but rather the inherent complexity and severity of the fracture cases selected to receive paralytic agents. Without random assignment, it becomes difficult to disentangle the true effect of the paralytic agents from the confounding influence of fracture severity.

Additionally, the reason for the specific request for the use of rocuronium or succinylcholine by the orthopaedic surgeon was not reported in operative notes, nor the precise time when the paralytic was administered. Increased anesthetic duration, fluoroscopic duration, and radiation exposure can be attributed to a difficult reduction which could be the reason for paralytic agent use. These various limitations of the retrospective study may be answered with a prospective study where the criteria for paralytic agent use can be set prior to the start of the study as well as anesthesia records. To our knowledge, this is one of the first orthopaedic research papers investigating the role of paralytic agents in the treatment of type III SCHFx in children. Although without a matched cohort or randomization within this study, this study more accurately highlights the variation in paralytic use for these fractures and the current lack of high-quality data to guide evidence-based practice. The limitations underscore the need for a prospective, randomized controlled trial, because only such a rigorously designed prospective could potentially overcome issues of selection bias and confounding to generate more solid evidence regarding if and how paralytic agents should be utilized for these fractures.

Paralytic agents to facilitate closed reduction of extension type III SCHFx did not correlate with shorter surgical times or other advantageous outcomes. However, the variables used to measure the ease and effectiveness of closed reduction with paralytic agents do not answer the question of why paralytic agents were administered to the patient. We recommend that further investigation is needed in determining the role of paralytic agents in type III SCHFx with a prospective randomized controlled trial utilizing similar variables that were measured in this study along with the reason for the administration of the paralytic agents. Further prospective randomized studies are needed to better understand the role of paralytic agents in the surgical treatment of type III SCHFx in children. By highlighting the current variability in practice and limitations of a retrospective analysis, this study provides the motivation and foundation to conduct future prospective, randomized research. Such studies would provide higher quality evidence to better guide clinical decision-making around the use of paralytic agents for type III supracondylar humerus fractures in children. The current investigation is an important first step towards resolving this unresolved clinical question.

Funding

There are no sources of funding for this project.

Declarations of competing interests

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: John Schlechter reports was provided by Children's Hospital of Orange County. John Schlechter reports a relationship with Arthrex Inc. that includes speaking and lecture fees. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors are very grateful to Ellie Gibbs and Rachel Davis for the editing of this manuscript and Tracey P. Bastrom for assisting with the statistical analyses of the study.

References

[1] Cheng JC, Ng BK, Ying SY, et al. A 10-year study of the changes in the pattern and treatment of 6,493 fractures. J Pedia Orthop 1999;19(3):344–50.
[2] Barr LV. Paediatric supracondylar humeral fractures: epidemiology, mechanisms and incidence during school holidays. J Child Orthop 2014;8(2):167–70.
[3] Holt JB, Glass NA, Shah AS. Understanding the epidemiology of pediatric supracondylar humeral fractures in the United States: identifying opportunities for intervention. J Pedia Orthop 2018;38(5):e245–51.
[4] GARTLAND JJ. Management of supracondylar fractures of the humerus in children. Surg Gynecol Obstet 1959;109(2):145–54.
[5] Rockwood CA, Wilkins KE, Beaty JH, et al. Fractures in children. In: Vol. 3. 4th ed. Philadelphia: J.B. Lippincott; 1984:680–1.
[6] Babal JC, Mehlman CT, Klein G. Nerve injuries associated with pediatric supracondylar humeral fractures: a meta-analysis. J Pedia Orthop 2010;30(3):253–63.
[7] Gottschalk HP, Sagoo D, Glaser D, et al. Biomechanical analysis of pin placement for pediatric supracondylar humerus fractures: does starting point, pin size, and number matter? J Pedia Orthop 2012;32(5):445–51.
[8] Abbott MD, Buchler L, Loder RT, et al. Gartland type III supracondylar humerus fractures: outcome and complications as related to operative timing and pin configuration. J Child Orthop 2014;8(6):473–7.
[9] Kocher MS, Kasser JR, Waters PM, et al. Lateral entry compared with medial and lateral entry pin fixation for completely displaced supracondylar humeral fractures in children. A randomized clinical trial. J Bone Jt Surg Am 2007;89(4):706–12.
[10] Skaggs DL, Cluck MW, Mostofi A, et al. Lateral-entry pin fixation in the management of supracondylar fractures in children. J Bone Jt Surg Am 2004;86(4):702–7.
[11] Pennock AT, Charles M, Moor M, et al. Potential causes of loss of reduction in supracondylar humerus fractures. J Pedia Orthop 2014;34(7):691–7.
[12] Popkin CA, Rosenwasser KA, Ellis HBJr. Pediatric and Adolescent T-type distal humerus fractures. J Am Acad Orthop Surg Glob Res Rev 2017;1(8):e040.
[13] Li M, Xu J, Hu T, et al. Surgical management of Gartland type III supracondylar humerus fractures in older children: a retrospective study. J Pedia Orthop B 2019;28(6):530–5.
[14] Valone LC, Waites C, Tartarilla AB, et al. Functional elbow range of motion in children and adolescents. J Pedia Orthop 2020;40(6):304–9.
[15] Goldfarb CA, Patterson JM, Sutter M, et al. Elbow radiographic anatomy: measurement techniques and normative data. J Shoulder Elb Surg 2012;21(9):1236–46.
[16] Brubacher JW, Dodds SD. Pediatric supracondylar fractures of the distal humerus. Curr Rev Musculoskelet Med 2008;1(3-4):190–6.
[17] Otsuka NY, Kasser JR. Supracondylar fractures of the humerus in children. J Am Acad Orthop Surg 1997;5(1):19–26.
[18] Mulpuri K, Wilkins K. The treatment of displaced supracondylar humerus fractures: evidence-based guideline. J Pedia Orthop 2012;32(Suppl 2):S143–52.
[19] McKenna P, Leonard M, Connolly P, et al. A comparison of pediatric forearm fracture reduction between conscious sedation and general anesthesia. J Orthop Trauma 2012;26(9):550–5.
[20] Varela CD, Lorfing KC, Schmidt TL. Intravenous sedation for the closed reduction of fractures in children. J Bone Jt Surg Am 1995;77(3):340. 5.
[21] Yang BW, Waters PM. Conscious sedation and reduction of fractures in the paediatric population: an orthopaedic perspective. J Child Orthop 2019;13(3):330–3.
[22] Gupta N, Kay RM, Leitch K, et al. Effect of surgical delay on perioperative complications and need for open reduction in supracondylar humerus fractures in children. J Pedia Orthop 2004;24(3):245–8.
[23] Donnelly M, Green C, Kelly IP. An inconvenient truth: treatment of displaced paediatric supracondylar humeral fractures. Surgeon 2012;10(3):143–7.
[24] Hager HH, Burns B. Succinylcholine chloride. [Updated 2020 Nov 16]. StatPearls [Internet]. Treasure Island (FL). StatPearls Publishing; 2021 (Available from:). 〈https://www.ncbi.nlm.nih.gov/books/NBK499984/〉.
[25] Strides Arcolab Limited. Anectine (Succinylcholine Chloride Injection) [package insert]. U.S. Food and Drug Administration. [cited 2020 Sep 25]; Available from: https://www.accessdata.fda.gov/drugsatfda_docs/label/2010/008453s027lbl.pdf.
[26] Rocuronium Bromide. (2021, July). http://www.pdr.net.
[27] Teva Pharmaceutical Industries, Rocuronium (Rocuronium Bromide Injection) [package insert]. U.S. Food and Drug Administration. [cited 2020 Sep 25]; Available from: https://www.accessdata.fda.gov/drugsatfda_docs/label/2008/078717s000lbl.pdf.
[28] Merck SharpDohme Corp., Bridion (Sugammadex Injection) [package insert]. U.S. Food and Drug Administration. [cited 2020 Sep 25]; Available from: https://www.accessdata.fda.gov/drugsatfda_docs/label/2015/022225lbl.pdf.