

Fully displaced pediatric supracondylar humerus fractures: Which ones need to go at night?

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Abstract

Background: Challenges remain in determining which displaced supracondylar humerus fractures are safe to postpone surgical treatment until daylight hours. The purpose of this study is to determine which characteristics can be identified to guide the timing of treatment of supracondylar humerus fractures.

Methods: 225 completely displaced Gartland extension type 3/4 supracondylar humerus fractures in healthy patients that presented between 6am and 7am were identified. Data were collected retrospectively. Data analysis included univariate, multivariable logistic regression and classification and regression tree analysis.

Results: 5% (78/225) underwent surgical treatment the night they presented, while 65% (147/225) were treated the next day. Overall complication rate was 6%, with no difference based on timing of surgery. 12% (28/225) presented with a motor nerve injury, while 6% (14/225) a “pink pulseless” extremity. Statistical analysis found the most reliable radiographic predictor to be the maximum displacement on the anterior–posterior or lateral view. Classification and regression tree analysis developed a clinical algorithm; patients with a “pink pulseless” extremity or motor nerve injury were recommended for surgery overnight, while those with an anterior–posterior or lateral view < 25 mm were recommended for surgery the next day.

Conclusion: This study provides guidance on the timing of treatment for displaced supracondylar humerus fractures that present overnight. We provide a simple algorithm with three key clinical predictors for timing of treatment: presence of a “pink pulseless” arm, presence of a motor nerve injury, and displacement of any cortex by at least 25 mm (anterior–posterior or lateral view). This provides a step forward to help practitioners make safer evidenced-based timing decisions for their patients.

Level of evidence: Prognostic Study, Level II.

Keywords: Supracondylar humerus fracture, pediatric elbow fracture, displaced elbow fracture

Background

Displaced supracondylar humerus (SCH) fractures are common in pediatric orthopedics, and are the most common pediatric fracture that undergoes surgical fixation. Mildly displaced fractures (modified Gartland type 2) can be safely postponed until daylight hours or even for a few days,¹ and some of the fully displaced fractures (modified Gartland type 3) can also be postponed safely until the next day.^{2,3} Yet, experts tend to agree that some pediatric SCH fractures are best not to leave until the next day.⁴ However, it has been difficult to universally identify the fractures that require more urgent reduction and fixation.

SCH fractures with a pulseless poorly perfused arm are clearly an indication for emergent treatment,⁵ and some surgeons consider a skin pucker to also signify the need for

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more urgency of reduction.⁶ Other authors have shown that SCH fractures that are reduced and fixed in the night hours have longer surgical time, malunion, and more likely need revision fixation.⁷ Complications of SCH fractures can be severe, including compartment syndrome and Volkmann's ischemic contracture.²

Motor nerve injuries sustained during SCH fractures have been noted to occur in 10%–20% of these injuries;^{2,8} however, this may be as high as 49% when just type 3 injuries are included.⁹ Most nerve injuries involve the median nerve and most fully recover after 2–3 months.¹⁰ However, it is not clear how the timing of surgery affects the nerve injury recovery, and whether the presence of a motor nerve injury should influence the timing of the surgery.

The orthopedic department at our institution treats several hundred SCH fractures each year. Our institution is a large tertiary care pediatric hospital, and we have a large group of fellowship trained pediatric orthopedic surgeons (approximately 15 surgeons in the call pool, with some variability year to year), and treat many SCH fractures each year. Some of the modified Gartland extension type 3 (and 4) fractures are left for surgery the next day, and some are chosen to go to surgery in the evening or night that they present. However, determining which of these fractures should be treated overnight and which can safely wait until the next day remains an art and not a science; there is variability even within our large group of subspecialists. To optimize outcomes for children with this injury, we need to improve our ability to more clearly identify presenting factors in SCH fractures that when treated with urgent nighttime surgery potentially results in a lower complication rate than those that wait until morning. Optimal care involves decreasing the risk for complications and optimizing the chance for nerve injury recovery. The purpose of this study is to determine which patient and fracture characteristics can be identified and provide guidance as to which SCH fractures are safe and potentially have lower complications when treatment is delayed until daylight hours versus which may have a lower complication rate with surgery that occurs in the evening or overnight.

Materials and methods

Institutional Review Board approval was achieved prior to initiation of this study.

This retrospective study included a consecutive series of patients who presented overnight to our institution and were treated for a completely displaced SCH fracture. SCH fractures were rated on the modified Gartland classification^{2,11} as determined by the orthopedic consult note from the Emergency Department (ED).

Inclusion criteria: All extra-articular fracture, isolated extension type SCH fractures classified by the modified Gartland classification^{2,11} as determined by the orthopedic consult note from the ED, treated surgically, with presentation to ED between 6 pm and 7 am, in patients aged 2–10.

Exclusion criteria include modified Gartland type 1 and 2 fractures, flexion type supracondylar, intra-articular fracture, patients who presented to Boston Children's Hospital (BCH) ED before 6 pm and after 7 am, age younger than 2 years or greater than 10 years at time of fracture, bilateral elbow fracture and ipsilateral upper extremity fracture (including "floating elbow"), and medical comorbidity that would influence care or surgical planning/timing. We also excluded patients with emergent vascular concerns as the decision to proceed with immediate surgery is clear in these patients.

These are similar inclusion and exclusion criteria of other studies of SCH fractures.^{12,13}

Complications assessed were infection requiring antibiotics or surgery, loss of reduction, return to the operating room, and/or iatrogenic nerve injury. Presence of any fracture-based nerve injury was also noted, as well as timing of its recovery. Open reduction of SCH fractures has substantial surgeon to surgeon variability within our group; therefore, this was not used as a complication. However, the use of open reduction (compared with closed reduction) was noted and compared across the treatment timing groups. These complications are useful to measure, but are not the greatest concern to those who treat this injury. What concerns pediatric orthopedic surgeons the most about displaced SCH fractures is the possibility for ischemic contracture and/or compartment syndrome, and this is what gets us out of bed at night to fix these injuries (not loss of reduction!). Therefore we modeled our algorithm around the "best practices" of our collective group of pediatric orthopedic surgeons: using clinical and radiographic characteristics, we determine which injuries inspired us to get out of bed and which we felt comfortable letting sit until the next day.

The neurovascular status of the patient's arm prior to surgery was carefully assessed by the clinical team and recorded for the study. Any emergent vascular concerns (i.e. pulseless white arm) were excluded from this study because the decision to proceed with immediate surgery is clear in these patients. Patients with "pink pulseless" extremities were included in this study.¹⁴ While neurologic status of an injured extremity typically involves assessment of both sensory and motor function, for this study, we chose to include only motor function or dysfunction. Children often have been shown to be unreliable in a sensory exam¹⁵ as they often respond to "please" the adult or, alternately, can be histrionic in nature; motor exam function, including weakness or dysfunction, is more reliable.

Demographic data, fracture specific data (including imaging and clinical notes), and clinical and radiographic follow-up were collected. Any adverse outcomes were noted. Radiographs were assessed both for degree of initial fracture displacement and loss of reduction after operative reduction and fixation. The preoperative radiographs showing the displaced fracture were comprehensively

Table 1. Radiographic measurements obtained using the best available lateral and AP radiographic images taken of the patient in the emergency room on night of presentation.

Code	Image used to measure	Description of measurement	Metric
L1	Best lateral view	The distance from the anterior edge of the shaft to the anterior edge of the fracture fragment	In millimeters
L2	Best lateral view	The distance from the posterior edge of the shaft to the posterior edge of the fracture fragment	In millimeters
L3	Best lateral view	Diameter of the proximal (shaft) fragment at the fracture edge	In millimeters
L4	Best lateral view	Diameter of the distal fragment at the fracture edge	In millimeters
L5	Best lateral view	Midshaft bone diameter	In millimeters
L6	Best lateral view	Distance of capitellum from anterior humeral line	In millimeters
L7	Best lateral view	Distance from anterior humeral “spike” to skin edge	In millimeters
L8	Best lateral view	Whether or not the distal fragment was “off ended”, that is, whether both the anterior and posterior cortices of the distal fragment lie behind the posterior cortex of the proximal shaft	Categorical
API	Best AP view	The distance from the medial edge of the shaft to the medial edge of the fracture fragment	In millimeters
AP2	Best AP view	The distance from the lateral edge of the shaft to the lateral edge of the fracture fragment	In millimeters
AP3	Best AP view	Diameter of the proximal (shaft) fragment at the fracture edge	In millimeters
AP4	Best AP view	The diameter of the distal fragment at the fracture edge	In millimeters
G	Both AP and lateral views	Each fracture was assessed for a global category based on one of the following: (1) posteromedial, (2) posterolateral, (3) not significantly displaced on AP view, (4) directly posterior, (5) rotational not reflected above, (6) other than as above, or (7) cannot tell or radiographs unavailable	categorical
MAPL	Both AP and lateral views	Maximum of L1, L2, API, AP2	In millimeters

AP: anterior–posterior; MAPL: maximum displacement on the anterior posterior or lateral view.

assessed and radiographic parameters measured. These parameters were determined after thorough literature review and an expert panel consensus for novel measures. Measurements were performed by a single fellowship-trained orthopedic surgeon, blinded to the timing of surgery; see Table 1.

Additional calculations and combinations of the above collected data were made for analysis purposes. This included a measurement of the maximal displacement of any single cortex, that is, the largest value of L1 (the distance from the anterior edge of the shaft to the anterior edge of the fracture fragment on the best lateral radiograph), L2 (the distance from the posterior edge of the shaft to the posterior edge of the fracture fragment on the best lateral radiograph), API (the distance from the medial edge of the shaft to the medial edge of the fracture fragment on the best anterior–posterior (AP) radiograph), or AP2 (the distance from the lateral edge of the shaft to the lateral edge of the fracture fragment on the best AP radiograph). We have called this novel indicator the maximum displacement on the anterior–posterior or lateral view (MAPL); see Figure 1 and Table 1.

If a reduction was performed at an outside institution prior to transferring to our institution, the radiographic measurements were taken from the post-reduction films as the decision for surgery timing was based on that new alignment. If imaging was so poor that measurements

could not be obtained from one or more views, then that data were left as missing data; only 10 patients were excluded because of poor imaging. This allowed us to assess a variety of measures of fracture displacement and rotation.¹⁶

Radiographs were also assessed for loss of reduction after operative fixation. Intraoperative fluoroscopic images were reviewed for pin configuration, as well as overall alignment of the distal humerus on both AP and lateral views. These were then compared with radiographs images taken 3–4 weeks postoperative. Baumann’s angle^{17–20} lateral rotation percentage,^{18,21,22} location of the anterior humeral line as it crosses the capitellum (not touching, anterior edge, anterior third, middle third, posterior third; 18.22) were assessed. A “loss of reduction” was determined if any of the above metrics changed between the intraoperative and postoperative radiographs: (1) change of Baumann’s angle $> 12^{\circ}$ ^{13,23} (2) change of lateral rotation percentage of $> 25\%$ ²¹ and (3) change of position of the anterior humeral line by at least two steps.¹²

Data analysis

Patient and injury characteristics were summarized for the cohort and stratified by timing of treatment. Primary treatment groups were patients treated early, between 6 pm and 7 am, versus patients who were delayed treatment to the

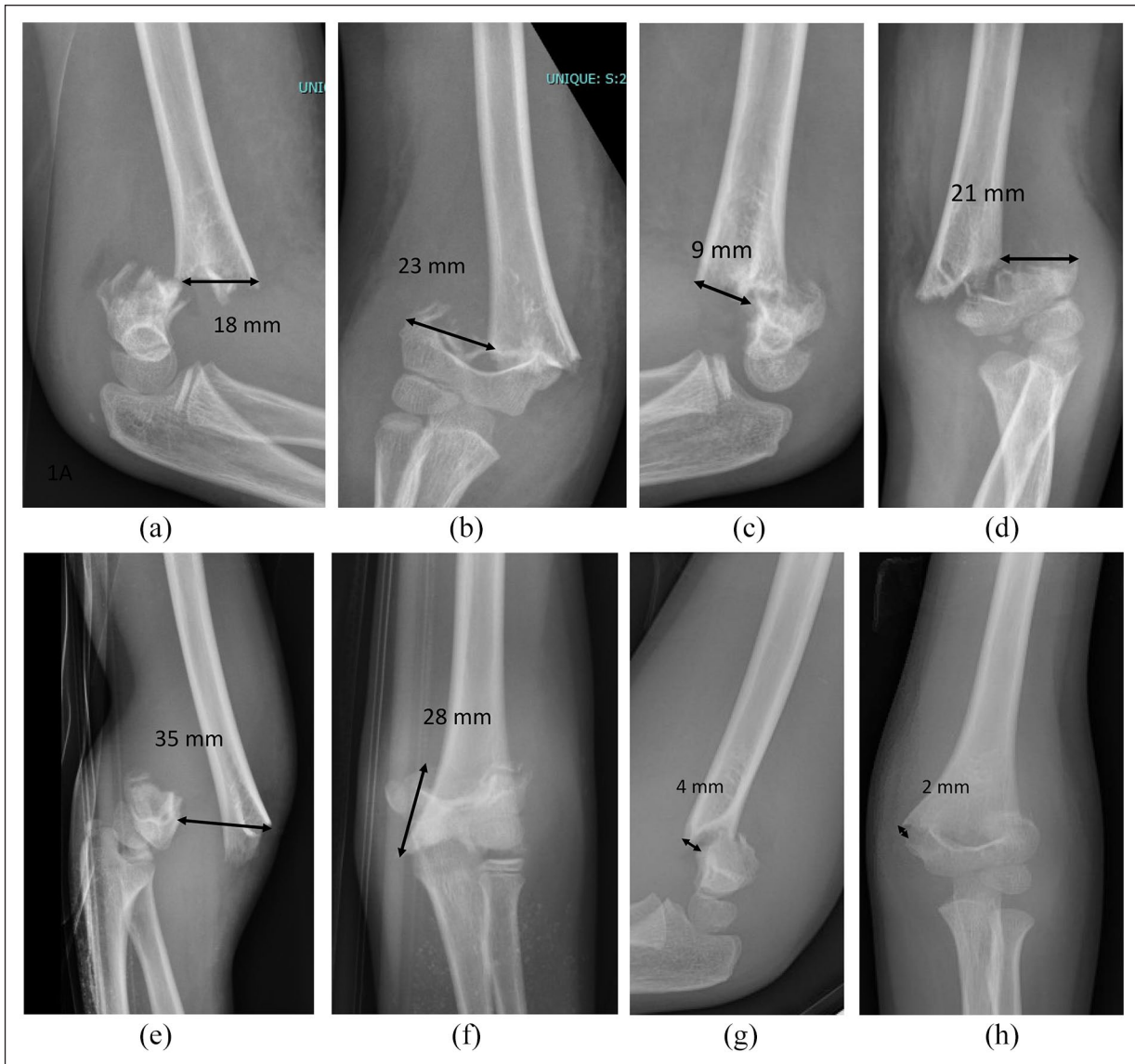


Figure 1. The maximum of the anterior-posterior or lateral (MAPL) measurement is obtained by measuring the maximum displacement of the most displaced fracture cortex on the anterior-posterior (AP) view as well as the maximum displacement of the most displaced fracture cortex on the lateral view. Then the larger of the two displacement is the MAPL. (a) Lateral and (b) AP are images from one patient; in this case the larger displacement is on the AP view and the MAPL is 23 mm. (c) Lateral and (d) AP are images from a second patient; in this case the larger displacement is also on the AP view and the MAPL is 21 mm. (e) Lateral and (f) AP are images from a third patient; in this case the larger displacement is on the lateral view and the MAPL is 35 mm. (g) Lateral and (h) AP are images from a fourth patient; in this case the larger displacement is on the lateral view and the MAPL is 4 mm.

next day, after 7 am. Comparisons in patient, injury, treatment, and radiographic characteristics were conducted across early and delayed timing groups using chi-square tests and Student's *t*-tests, as appropriate. Classification and regression tree (CART) analysis was used to visualize and identify cutoff values of continuous injury and radiographic characteristics that optimally discriminated between patients treated early versus delayed. The CART analysis found that a combined radiographic measurement that maximized four displacement measurements

was the most discriminatory for treatment time (Table 1). A final treatment algorithm for injuries treated early versus delayed based on injury and radiographic parameters in our data are described. The sensitivity, specificity, and the area under the receiver operating characteristic (ROC) curve were estimated for the final algorithm to demonstrate the utility and discriminatory abilities of the algorithm. Multivariable logistic regression using a penalized maximum likelihood was used to determine any demographic, injury, or treatment characteristics associated

Table 2. Patient and injury characteristics for all subjects and stratified by treatment timing.

Characteristic	All injuries (n=225)		Early (n=78)		Delayed (n=147)		p
	Freq.	(%)	Freq.	(%)	Freq.	(%)	
Age at injury (years; mean (SD))	6.3	(2.0)	6.4	(1.7)	6.2	(2.2)	0.34
Sex (% male)	106	(47%)	36	(46%)	70	(48%)	0.83
Ethnicity							
Hispanic	12	(5%)	7	(9%)	5	(3%)	0.96
Not Hispanic	174	(77%)	57	(73%)	117	(80%)	
Unknown/not reported	39	(17%)	14	(18%)	25	(17%)	
Race							0.19
White	144	(64%)	49	(63%)	95	(65%)	
Black/African American	10	(4%)	2	(3%)	8	(5%)	
Asian	22	(10%)	5	(6%)	17	(12%)	
Native Alaskan	1	(0%)	0	(0%)	1	(1%)	
Other/unknown	48	(21%)	22	(28%)	26	(18%)	
Injury characteristics							
Injured side (% right)	142	(63%)	51	(65%)	91	(62%)	0.61
Swelling	224	(99.6%)	78	(100%)	146	(99%)	0.99
Puckering	13	(6%)	9	(12%)	4	(3%)	0.01
Nerve injury	28	(12%)	23	(29%)	5	(3%)	<0.001
Median only	18	(62%)	17	(59%)	1	(10%)	
Radial only	7	(25%)	4	(14%)	3	(30%)	
Ulnar only	1	(4%)	0	(0%)	1	(10%)	
More than one nerve	2	(7%)	2	(7%)	0	(0%)	

SD: standard deviation.

with an increased likelihood of complications. Odds ratios (ORs) along with 95% confidence intervals (CIs) were estimated for significant effects.

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Results

A total of 225 SCHFXs presented to the ED between 6 pm and 7 am at an average age of 6.3 years (range 2.1–10.9 years; Table 2). Of these, 78 (35%; 95% CI=29–41%) were treated early at a median 2.5 h after presentation and 147 (65%) were delayed treatment to a median of 11.7 h after presentation (Table 2).

There was no association detected between patient demographics and the treatment timing including age ($p=0.34$), sex ($p=0.83$), ethnicity ($p=0.96$), or race ($p=0.19$) (Table 2). Bivariate comparisons of radiographic measures found that patients treated early had higher indicators of radiographic displacement when measures were assessed independently or in combination (Table 3). Specifically, MAPL had a mean of 22.2 mm (SD 9.9) for those patients treated early and 14.3 mm (SD 8.0) for those patients delayed until the next day (<0.001).

In all, 28 subjects (28/225, 12%) had concomitant nerve injury: 18, medial nerve; 7, radial nerve; 1, ulnar nerve;

and 2, more than one nerve (Table 3). There was no difference detected in the time to nerve recovery across treatment timing groups ($p=0.36$). One patient was missing vascular status; 14 subjects (14/224, 6%) had abnormal vascular status at presentation and all were treated early.

Complications

In total, there were only 14 complications (14/225; 6%; 95% CI=4%–10%; Table 4). Six of the 147 (4%) delayed treatment fractures experienced at least one complication compared with 8 of the 78 (10%) early treated fractures ($p=0.08$). Multivariable analysis determined that age was the only factor associated with an increased likelihood of complication when controlling for treatment timing ($p=0.35$), vascular status ($p=0.75$), nerve injury ($p=0.14$), and MAPL displacement greater than 25 mm ($p=0.12$). More specifically, it was found that for each year of decrease in age at injury, the odds of complication increased by 72% (OR=1.72; 95% CI=1.16–2.56; $p=0.007$).

Treatment algorithm

CART analysis found that vascular status, nerve injury, and the MAPL (with a cutoff value of 25 mm) were the most indicative of treatment timing (Figure 2). Based on our cohort, 100% of injuries with abnormal vascular status

Table 3. Radiographic characteristics by treatment timing.

Radiographic characteristic	Early (n = 78)		Delayed (n = 147)		p
	Mean	(SD)	Mean	(SD)	
MAPL: Max (L1, L2, AP1, AP2)	22.2	(9.9)	14.3	(8.0)	<0.001
L1	17.6	(9.6)	12	(7.2)	<0.001
L1/L5	1.3	(0.6)	0.9	(0.5)	<0.001
L1 + L2	33	(18.8)	19.4	(12.7)	<0.001
(L1 + L2)/L5	2.4	(1.3)	1.4	(0.9)	<0.001
L1 + L2 + AP1 + AP2	62.4	(31.2)	37.4	(26.0)	<0.001
(L1 + L2 + AP1 + AP2)/L5	4.6	(2.3)	2.8	(1.8)	<0.001
L5	13.7	(2.2)	13.5	(2.1)	0.55
L3/L4	1.2	(0.4)	1.2	(0.4)	0.98
ABS(1 L3/L4)	0.3	(0.3)	0.3	(0.3)	0.51
AP3/AP4	1.1	(0.5)	1.1	(0.2)	0.19
ABS(1-AP3/AP4)	0.2	(0.5)	0.1	(0.2)	0.10
L6	21.3	(12.0)	13.9	(9.4)	<0.001
L7	21	(11.5)	28.5	(10.0)	<0.001
L8 (n, (%))					<0.001
Yes	40	(53%)	25	(17%)	
No	26	(35%)	103	(71%)	
Borderline	9	(12%)	17	(12%)	
GLOBAL					0.07
Posteromedial	24	(31%)	33	(22%)	
Posterolateral	31	(40%)	45	(31%)	
Not significantly displaced on AP view	0	(0%)	10	(7%)	
Directly posterior	17	(22%)	50	(34%)	
Cannot tell/X-ray unavailable	5	(6%)	9	(6%)	
Rotational	1	(1%)	0	(0%)	

SD: standard deviation; MAPL: maximum displacement on the anterior–posterior or lateral view; AP: anterior–posterior.

Table 4. Treatment and outcome characteristics by treatment timing groups.

Characteristic	Early (N = 78)		Delayed (N = 147)		p
	Mean	(SD)	Mean	(SD)	
Time to treatment (h; mean (SD))	3.1	(1.7)	11.8	(3.1)	
Open reduction	9	(12%)	4	(3%)	0.01
On-call surgeon experience level					<0.001
0–4 years	8	(10%)	9	(6%)	
5–9 years	36	(46%)	46	(31%)	
10–14 years	28	(36%)	50	(34%)	
15+ years	6	(8%)	42	(29%)	
Complication (at least 1)	8	(10%)	6	(4%)	0.08
Loss of reduction	7	(9%)	5	(3%)	0.09
Infection	0	(0%)	1	(1%)	>0.99
Return to OR	1	(2%)	0	(0%)	>0.99
New nerve issue	1	(1%)	0	(0%)	>0.99
Nerve injury	23	(29%)	5	(3%)	
Timing of nerve recovery (n = 28)					0.36
Immediately postoperative	2	(9%)	2	(40%)	
Prior to hospital discharge	2	(9%)	0	(0%)	
Post hospital discharge, but < 1 month FU	4	(17%)	1	(20%)	
≥ 1 month but < 3 month FU	5	(22%)	1	(20%)	
≥ 3 month FU	6	(26%)	1	(20%)	
Lost to FU, recovery not recorded	4	(17%)	0	(0%)	

SD: standard deviation; OR: odds ratios; FU: follow-up.

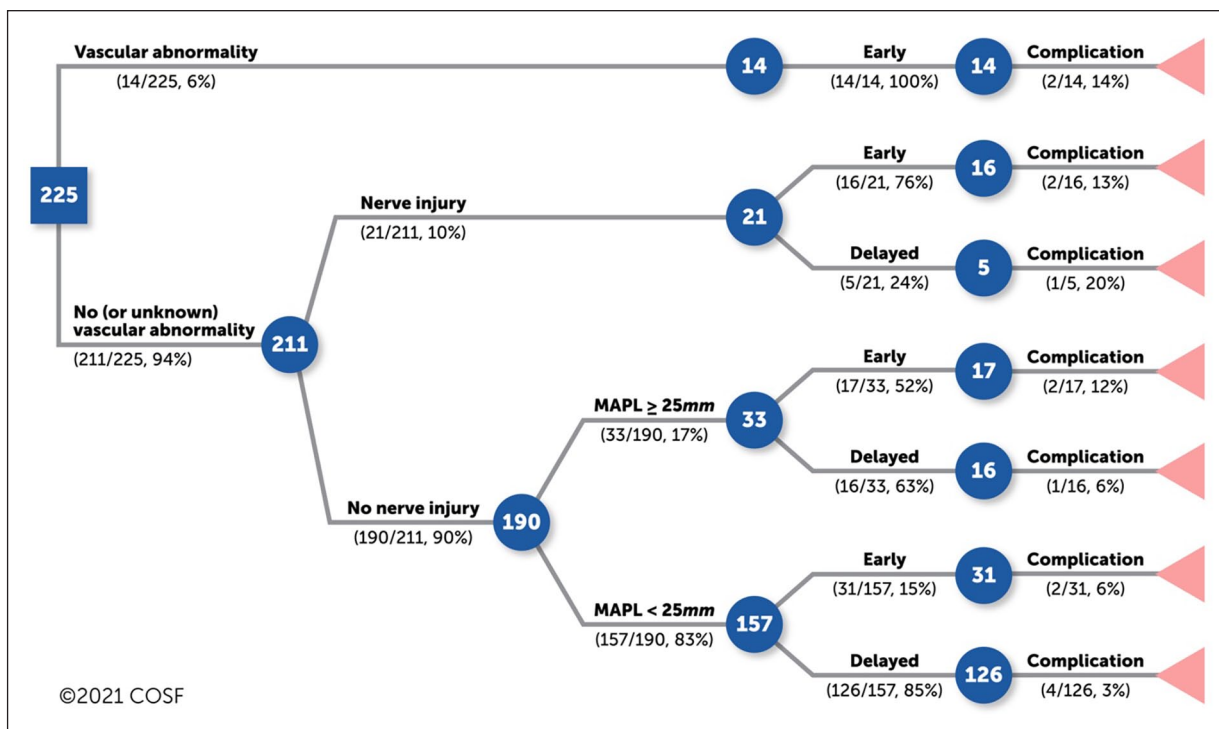


Figure 2. Study data flow through treatment algorithm. Data were analyzed with classification and regression tree (CART) analysis based on when our group of pediatric orthopedic surgeons chose to treat the patients in the cohort, based on clinical and radiographic characteristics (early = overnight, delayed = postponed until the next day). Complication rates are also presented but were not used to create this algorithm.

(14/224, 6%) were treated early. Of these, 2 (2/14, 14%) experienced a complication. Of the remaining 211 injuries, 21 (21/211; 10%) had a concomitant nerve injury. Of these, 16 (16/21; 76%) were treated early, 2 (2/16; 13%) of which experienced a complication. The remaining 5 (5/21; 24%) were delayed treatment and 1 (1/5; 20%) injury resulted in complication. There were 190 SCHFx (190/225; 84%) with normal vascular status and no nerve injury. Of these, 33 (33/190; 17%) had maximal displacement (MAPL) of 25 mm or more: 17 (17/33; 52%) of these maximally displaced injuries were treated early and 16 (48%) were delayed. Of the early treated injuries, 2 (2/17; 12%) experienced a complication and 1 of the delayed treated injuries (1/16; 6%) experienced a complication. The remaining 157 injuries had normal vascular status, no nerve injury, and MAPL <25 mm. Of these, 31 (31/157; 20%) were treated early and resulted in 2 complications (2/31; 6%). The other 126 injuries (126/157; 80%) were delayed treatment and result in 4 complications (4/126; 3%).

Using this treatment algorithm and applying it to our current cohort (see Figure 3) yielded a sensitivity of 61% and a specificity of 86%. Moreover, the algorithm would have indicated that 68 of our fractures should have been treated early. In reality, we delayed 21 of those injuries (only 2 of which experienced a complication). Conversely, the algorithm would have indicated that 156 injuries

should have been delayed in treatment, but we treated 30 of these early (only 2 of which experienced a complication). The area under the ROC curve was 0.76 (95% CI=0.69–0.82), indicating that this algorithm would be able to discriminate between an SCHFx that should be treated early versus delayed with 76% accuracy.

For patients with normal neurovascular status but large displacement (MAPL ≥ 25), the complication rate was slightly higher if surgery was done in the evening or overnight (12%), compared with the next day (6%). For patients with a smaller displacement (MAPL < 25 mm), the patients with evening or overnight surgery had a higher complication rate (6%) compared with those with delayed surgery (3%); see Figure 2.

Puckering

A total of 13 SCHFx (13/225, 6%) presented with skin puckering. Of these injuries, 9 were treated early; 2 with vascular abnormality, 2 with nerve injury, and 4 with maximal displacement greater than 25 mm (some patients had more than one of these criteria). The other 4 fractures were delayed in treatment; none with vascular abnormality, none with nerve injury and none with maximal displacement greater than 25 mm. No fracture with puckering experienced a complication.

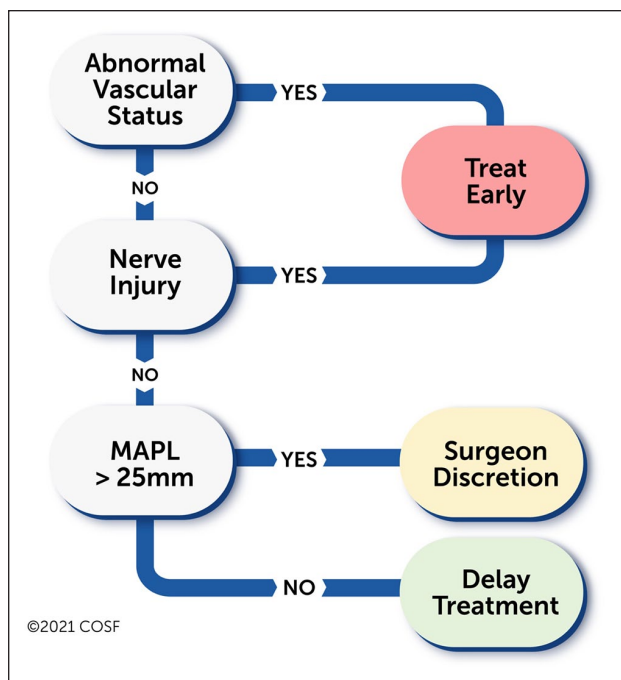


Figure 3. Proposed treatment timing for SCHFx based on vascular status, nerve injury, and maximal displacement. This treatment timing algorithm is based on the combined “best practices” of our large pediatric orthopedic group. “Treat Early” means that surgery is recommended in the evening or overnight. “Delay Treatment” means that most of these injuries are safe to postpone for treatment the next day.

Provider experience

All providers were fellowship trained, board certified (or board eligible) pediatric orthopedic surgeons. The majority of providers on call had less than 15 years’ experience (177/225, 79%) with a median of 9 years (IQR, 6–14) of experience since completion of orthopedic fellowship. Those with 15 or more years of experience had a median of 17 years (IQR, 15–19 years) and were significantly less likely to treat fractures early. Less experienced surgeons were 14 times more likely to treat early compared with those with 15+ years of experience (OR=14.0; 95% CI=3.2–60.4; $p < 0.001$), controlling for vascular status, nerve injury, and MAPL > 25 mm. No difference was detected across experience groups with respect to complications (<15 years, 10/177=6%; 15+ years, 4/48=8%; $p=0.50$).

No patients in this series went on to a compartment syndrome.

Discussion

The timing of treatment of fully displaced SCH fractures remains controversial. While many of these injuries can be safely postponed until the next day,^{3,24–28} all series have

some fractures that still had overnight treatment, indicating that there are some of these fractures severe enough to warrant evening or overnight surgery. However, the guidance on which of these fully displaced modified Gartland type 3 or 4 injuries are best treated at night, and which can safely be postponed until the next day is less clear.

In our series, 35% of patients were treated in the evening or overnight for their fully displaced SCH fracture. There was an overall complication rate of 6%, with no difference in complication rate between those that were treated in the evening or overnight and those that were treated the next day. This is very similar to the reports by other authors; we also included measured loss of reduction which was not included in most other studies. Schmid et al. reported a complication rate of 10% in their series of both type 2 and 3 fractures, with no difference in complication rate based on the timing of surgery. Shon et al. stratified their Gartland type 3 SCH by < 6 h from injury, 6–12 h from injury, and 12–24 h from injury. They found no difference in those with delay from those addressed immediately.²⁷ Paci et al.⁷ retrospectively reviewed 263 pediatric operative SCH fractures and found that 29% were pinned during daytime hours while 71% were pinned after hours (4 pm–6 am and weekends). They had 32 surgeons in the study, 9 of whom were pediatric orthopedic surgeons. After hours were more likely to be more severe (Gartland type 3/4) injuries, and less likely to be performed by a pediatric orthopedic surgeon. They found that late-night surgery (11 pm–6 am) was independently associated with increased odds of malunion, but not other complications.⁷

In our series, we went on to stratify complications based on preoperative factors to help elucidate which fractures may be safer going in the evening or overnight and which may be safer to wait until the next day. This created a model algorithm that we present (Figure 3) and stratify based on the presence (or absence) of a “pink pulseless” extremity, the presence (or absence) of a motor nerve injury, and the presence (or absence) of displacement of at least one cortex of at least 25 mm on radiographs (MAPL). We found that we treated all patients with a “pink pulseless” extremity overnight, and found that most patients with a motor nerve injury were treated overnight, and if they were, they were less likely to have a complication compared with those that were delayed until the next day. The group with no motor nerve or vascular compromise and wider displacement (MAPL ≥ 25 mm) were relatively equally split between those that went to surgery early (overnight) versus delayed (the next day). These generally had higher complication rates than those less displaced (MAPL < 25 mm) fractures; these can be difficult injuries, so we recommend that the surgical timing be at the discretion of the surgeon. This highlights that there remain factors in this group that are difficult to identify that impact the treatment and outcome of these injuries, emphasizing

that there does remain some surgeon discretion in treatment timing decisions.

While some authors found soft tissue envelope to be an important marker for determining the need for urgent surgery,^{6,29} and in our study presence of a skin pucker was more likely to be surgically treated early, but because they had concomitant factors (vascular insult or motor nerve injury) that drove the management, the presence of a pucker did not independently hold up in the model. Some of our radiographic measures were proxy for skin at risk (L7) phenomena, but also were not powerful enough to hold up in the modeling process compared with other injury and displacement factors.

Concerns with vascular perfusion remain paramount for those who treat these injuries. For this study, we excluded patients with avascular arm or hand, as the decision for surgical timing in those cases is quite clear. We included patients with a “pink pulseless”¹⁴ arm and found, not surprisingly, that all of these patients were treated the night they presented. We have included them in the algorithm appropriately.

Nerve injuries have also always been of concern with SCH fractures. While the recovery of most motor nerves can be expected by 6 months post injury,¹⁰ lack of sensory feedback to the compartments can mask a compartment syndrome. Barrett et al. assessed patients with Gartland type 3 SCH fracture-based injuries and isolated anterior interosseous nerve injuries. They found no difference in time to nerve recovery based on time to surgery.³⁰ There were no instances of compartment syndrome in their series, and they also excluded patients with sensory only changes from their series.³⁰ Shon et al.²⁷ in their series of only Gartland type 3 injuries had a preoperative fracture-based nerve deficit rate of 14.7%. This is similar to our injury-based (motor only) nerve injury rate of 8%. Interestingly, while we found nerve injury recovery was not associated with the timing of surgery, we found that the presence of a motor nerve injury was important for determining the timing of surgery. It is not clear why this was such a strong driver of the model; however, it may serve as a marker of overall injury severity.

Many authors use the conversion to open reduction as a negative outcome from surgical delay of SCH fractures.²⁴⁻²⁶ However, this may not be the best metric to determine the optimal timing of fracture care. Open reduction could relate to injury-related factors including displacement or neurovascular status, could be related to swelling due to increased wait time from injury to surgery, or could be independently related to surgeon preference. Iyengar et al.²⁴ found no difference in conversion for open reduction of Gartland type 3 SCH fractures treated more than 8 h after fracture than those treated less than 8 h after fracture. Schmid et al. also retrospectively reviewed both Gartland type 2 and 3 SCH fractures and stratified based on time from injury to surgery. They found surgical delay

had no influence on rates of open surgery, complications, or poor outcome.²⁵ Sibinski et al.²⁶ used a 12 h from fracture time cutoff to determine delayed surgery, but found no difference in open reduction, operating time, length of hospital stay, or outcome. We chose not to include open reduction as a negative outcome of surgery, as the variability of this is considerable within our group. Nonetheless, we found a much higher rate of open reduction in the fractures that had surgery in the evening or overnight hours.

Provider experience in treating SCH fractures has been previously addressed by other authors. Abdel Karim et al.³¹ found that cross-pin fixation constructs showed enhanced stability compared with lateral-entry only constructs in the hands of junior trainees, but this was not compared with a more senior group. Liu et al.³² found orthopedic fellows needed 15 cases of SCH fractures to be satisfactorily unsupervised for these cases. We found that surgeons with more experience (>15 years) were less likely to perform surgery overnight than their younger (<15 years experience) colleagues. However, there were some elbow fractures that compelled even our most senior surgeons to operate in the wee hours of the night.

We also found that risk for complication from treatment of SCH fracture went up as patient age decreased ($p=0.007$). This was surprising to us and we know of no other literature that has reported a similar result. Further investigation is warranted.

In 2011, the American Academy of Orthopaedic Surgeons put together an appropriate use criteria (AUC) for pediatric SCH fractures and published in 2012.³³ They were unable to recommend for or against a time threshold for surgery in patients without neurovascular injury (Recommendation 5) and did recommend emergent reduction in patients with a poorly perfused hand (Recommendation 7). They did not comment on the timing of surgery in the presence of an isolated nerve injury or any particular displacement criteria in these patients.

There are several weaknesses of this study. We treated all patients who presented with a “pink pulseless” extremity immediately overnight, thus limiting the variability of this factor. In addition this was a retrospective study, and with that come inherent weaknesses, including the potential for uncontrolled confounding and missing data, including comprehensive surgeon-based decision making, the availability of the operating room for evening or overnight surgery, whether or not there was operating room availability early the next day, and other subtle factors influencing the timing of surgery that were not apparent in the medical record. We do not have guaranteed next-day first case start time at our institution; there may therefore be a bias for surgery to be done in the evening to ensure next-day delays are not encountered. Algorithm creation is also open to bias as it optimizes the data available for this cohort of patients. This necessitates the testing of any particular new algorithm on a new subset of patients for

further validation. This is a single institution study, and the results may not be entirely generalizable to other institutions; however, the large number of surgeons involved does lend strength to the potential generalizability.

Summary

This study provides additional guidance on the timing of treatment for fully displaced pediatric SCH fractures, in an effort to move this from the “art” of medicine into data-driven decision making. Determining which of these fractures should be treated in the evening or overnight and which can or should safely be postponed until the next day remains one of the important difficult decisions in pediatric orthopedic trauma care and remains at the discretion of the treating surgeon. We have proposed a simple algorithm (Figure 3) with three key clinical predictors for timing of treatment: presence of a “pink pulseless” arm, presence of a motor nerve injury, and displacement of any cortex by at least 25 mm (MAPL). Our strongest findings and recommendations are that patients with a motor nerve palsy are most likely to benefit from evening and overnight intervention to reduce complication rates and those without a motor palsy or MAPL < 25 mm had lower complication rates with delayed surgery. Our data are less clear in patients with intact motor nerve and vascular status but high displacement (MAPL ≥ 25). Surgeon discretion is always important, and particularly more so in this group of patients. Any decision tool should be used appropriately and carefully in the clinical arena. Further validation of this algorithm is essential. However, this provides a step forward to help practitioners who care for these difficult injuries make safe decisions for their patients.

Author contributions

S.T.M. did the data design, acquisition, interpretation, and manuscript drafting and revision.

P.E.M. conducted the data design, analysis, and critical revision of the manuscript. J.P. carried out data acquisition and critical revision of the manuscript. N.S. was responsible for data acquisition and analysis, and critical revision of the manuscript. C.V. carried out data design and interpretation and critical revision of the manuscript. All authors provided final approval of the manuscript version submitted.

Compliance with ethical standards

- The Research is compliant with the Helsinki declaration.
- Institutional review board approval was obtained prior to initiating the research project.
- Informed consent was waived in the retrospective project.

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