

**FEASIBILITY OF THE PRE-OPERATIVE NEUROVASCULAR EXAMINATION
IN PEDIATRIC ELBOW FRACTURES**

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Dedication:

This thesis is dedicated to my father, Balbinder Johal, my mother Nanki Johal, and to my brother Arjun Johal. Without their love and support I would not have come this far.

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Abstract:

A detailed pre-operative examination of a child's neurovascular status following pediatric elbow fractures is critical to the assessment of these injuries. Without proper documentation of the preoperative exam, apparent postoperative changes in the neurovascular examination may be difficult to determine, and may dictate different treatment strategies. The reported incidence of neurologic (11.3%) and vascular (0.3-4.6%) injury associated with supracondylar fractures underscores the importance of the preoperative exam. The purpose of this prospective study was to determine how frequently a complete neurovascular exam could be completed in children with elbow fractures. A detailed, specific elbow fracture History and Physical form was developed for prospective use on all pediatric elbow fractures in a tertiary care pediatric trauma hospital from 2013 through 2014. Specific neurovascular exam criteria were documented in an easily used checklist form. Demographic data collected included age, BMI, mechanism of injury, fracture type, comorbidities, pre-operative pain management, and the operative procedure performed. There were 163 patients meeting the inclusion criteria. Attempted neurovascular (NV) exam was documented in 146 of these patients (89.6%). A clinically reliable, complete NV exam was possible in 104 patients (71.2%). In the remainder of the children, the clinician could not determine at least one aspect of the neurovascular exam. A significant correlation was found between age of the subject and ability to obtain a complete exam, with younger children less than age 5 being more likely to have incomplete information on the NV exam ($p < 0.000001$). Gender, BMI, fracture type, pre-assessment pain control, and potential language barriers had no effect on whether or not the exam was complete. Although a complete and detailed neurovascular examination is considered necessary when evaluating pediatric elbow fractures, over a fourth of our patients (29%) were unable to reliably participate in a full preoperative neurovascular exam. Younger children (less than 5 years of age) were less likely to participate in a complete neurovascular assessment. Neurovascular examinations in the setting of elbow fractures in children less than five years of age were unreliable and incomplete.

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Introduction and Significance

As a group, elbow fractures are the most common type of fractures within the pediatric population. Supracondylar humerus (SCH) fractures alone are the second most common type of fracture found in these patients.¹ They account for 16.6% to 17.9% of all childhood fractures and are the most commonly occurring fractures in the first 7 years of life.² Incidence of these injuries has been estimated between 120³ and 177⁴ per 100,000 children, with an increased incidence recorded among males as compared to females. Extension type injuries are estimated to account for 96% to 98% of all SCH fractures, with flexion type injuries comprising the remaining 2% to 4%.⁵

In addition to their high prevalence, the unique and complex anatomy of the elbow has made SCH fractures a source of anxiety and interest among orthopaedic surgeons.⁶ The distal portion of the humerus is bounded by the median nerve and brachial artery anteriorly, the radial nerve laterally, and the ulnar nerve medially. Also of note is the anterior interosseus nerve, a purely motor branch of the median nerve that arises 3.5-5cm distal to the elbow and which supplies branches to flexor pollicis longus, pronator quadratus, and the radial portion of flexor digitorum profundus.^{7,8} Damage to these structures in association with SCH fracture has been well documented in the literature.

Traumatic neurologic injuries are the most common sequelae of SCH fractures and have been recorded as occurring in 5.5% to 31% of pediatric patients.⁹⁻¹² In a recent meta-analysis of all SCH associated neuropraxias, Babal et al⁵ found traumatic neuropraxias to occur at an overall event weighted rate of 11.3%. In their study, the nerve most commonly involved in traumatic neuropraxia was the anterior interosseus (4.6%), followed by the radial (4.1%), the median (3.0%), and the ulnar (2.6%). Involvement and injury can occur either as the result of direct contusion to the nerves^{8, 13} or from the occurrence of traction type injuries in displaced fractures.¹⁴ Traumatic vascular injuries affecting the brachial artery are found less frequently, with most studies recording their incidence in .3% to 4.6% of SCH fractures^{13, 15-17} although some studies estimate their occurrence at nearly 20%.¹⁸

Neurovascular compromise is cause for concern due to the disastrous outcomes that may result from non-recognition of such injuries. Although the majority of neurologic injuries will resolve spontaneously, a subset can produce marked and lasting effects on motor and sensory function if left untreated. As noted by Sinikumpu et al¹⁹, these lasting neuropathies can produce major morbidity due to the disease entity's harmful effects on dexterity and subsequent interference with daily life. Mubarak et al²⁰ identified SCH fractures and the attendant complications of the brachial artery as the most common initiating cause of Volkmann's contracture in the arm. Other studies have implicated injuries to the brachial artery in the development of compartment syndrome, forearm claudication, cold intolerance, thrombus embolization, retarded development of the limb, and long-term loss of function.¹⁸ The effects of all of these sequelae are compounded by the long life expectancy of pediatric patients.¹⁹

For the avoidance of such complications, the appropriate selection of treatment type and timing, as well as the provision of a baseline measurement against which post-operative function can be compared, the performance of a thorough pre-operative neurovascular exam is considered critical by the vast majority of orthopaedic surgeons.^{6-10, 13, 17, 20, 21} Unfortunately, actually conducting such an exam with a pediatric patient can be difficult because of pain and anxiety.^{5-7, 13, 14, 22} In very young patients, issues with understanding and compliance of can also present challenges.²¹

Rationale and Aim

Despite recognition of the importance of pre-operative neurovascular examination in SCH fractures and widespread acknowledgement of the difficulty in performing such an assessment in pediatric patients, relatively little analysis has been done of the rate at which orthopaedic surgeons are able to thoroughly evaluate the pre-operative neurovascular status of pediatric patients with SCH fractures. There thus exists a gap in the literature with regards to analysis of the rates at which trained orthopaedic surgeons are able to obtain thorough pre-operative neurovascular examinations in pediatric patients presenting with SCH fractures. This

study aims to review the performance of orthopaedic surgeons at a large tertiary care hospital in the Southwest United States in an attempt to provide new data as to the rate at which these exams are actually conducted and documented. Furthermore, we have attempted to determine which factors are associated with the inability to obtain complete and accurate preoperative neurovascular examinations in pediatric patients with elbow fractures. This information will allow us to better understand issues surrounding the proper care of pediatric elbow fractures and may enable the development of treatment protocols that would help to optimize care for these patients.

Materials and Methods

This is a prospective chart review study of all pediatric patients who presented to the Center for Pediatric Orthopaedic Surgery at Phoenix Children's Hospital for reduction of elbow fractures between January 1, 2013 and February 28, 2014. Subjects were identified via hospital ICD-9 codes and discharge diagnoses. Inclusion criteria were all patients under 18 years old who underwent surgical correction of elbow fractures. Exclusion criteria were patients older than 18 years old and patients undergoing surgery for reasons other than elbow fractures. 163 patients with surgically managed elbow fractures were identified.

Data was sourced from the PCH EMR directly from patient charts. Medical records were reviewed for surgeon completion of elbow specific orthopaedic history and physical form, chief complaint, patient age, gender, race/ethnicity, height, weight, BMI and medical comorbidities. Records were also reviewed for surgeon documentation of pre- and post- operative nerve sensitivity, motor function, vascular perfusion, specific mechanism of injury, degree of injury using the modified Gartland classification as originally described by Gartland²³ with the addition of a fourth type as proposed by Leitch²⁴ et al, pre-operative medical treatment and management, and operative procedure performed. All assessments were performed by board certified, fellowship trained, pediatric orthopaedic surgeons.

All collected data was de-identified and stored electronically on encrypted server, located within physically locked offices on-site at Phoenix Children's Hospital.

Data was analyzed using simple, univariate analysis including descriptive statistics, t-tests, and chi-square measures for group comparisons. Statistical significance was defined as $p < 0.05$.

This study was approved by the Phoenix Children's Hospital Institutional Review Board as well as the University of Arizona Institutional Review Board.

Results

A total of 163 patients were identified as meeting the inclusion criteria within the 14-month study period. Of these patients, 17 had no documented preoperative neurovascular exam attempted. Study analysis was performed upon the 146 remaining patients upon whom an attempt at examination was documented. See Table 1 for selected clinical data. The average age at the time of examination was 5.9 years (range: 9 months to 16 years). Gender distribution was roughly equal, with 71 (48.6%) male patients, and 75 (51.4%) female patients. Hispanics were the most represented ethnicity at 69 (47.3%) patients, followed by Caucasians at 56 (38.3%) patients. 11 (7.5%) patients were Native American, 6 (4.1%) identified as African American, 2 (1.4%) were Asian, and 2 (1.4%) identified as Other. 31 (21.2%) patients had pre-existing medical comorbidities and 8 (5.5%) had sustained prior orthopedic injury (dislocation or fracture). 140 (95.9%) patients received pain medication prior to preoperative neurovascular examination, 6 (4.1%) did not. Surgeons utilized the Elbow Specific Orthopedic H&P Form for 136 (93.2%) patients, documenting neurovascular status within the clinical note in the remaining 10 (6.8%) patients.

Of the 146 patients analyzed, 54 (36.9%) sustained Gartland Type II Supracondylar Humerus Fractures. 69 (47.3%) sustained Gartland Type III Supracondylar Humerus Fractures. 15 (10.3%) patients sustained lateral condyle fractures, and 8 (5.5%) sustained medial condyle fractures. Left sided injuries were more common, with 78 (53.4%) left sided fractures and 68 (46.6%) right sided fractures. 7 (4.8%) patients presented with concomitant fractures of the ipsilateral radius sustained via the same mechanism as the elbow fracture. 127 patients were treated using closed reduction and percutaneous pinning. 15 patients required open reduction with internal fixation, and 4 patients required open reduction following by percutaneous pinning.

Surgeons were able to obtain and document complete preoperative neurovascular examination in 104 (71.2%) patients.

When examining the median nerve for motor and sensory function, surgeons documented themselves as unable to fully assess the nerve for 34 patients. Of these 34 patients, 22 patients could not be assessed for either motor or sensory function, 8 could be

assessed for motor function but not sensory, and 4 could be assessed for sensory function but not motor. 3 patients were documented as having normal motor function and abnormal sensory function. 2 patients had documented abnormalities in both motor and sensory function.

When examining the radial nerve for motor and sensory function, surgeons documented themselves as unable to fully assess the nerve for 34 patients. Of these 34 patients, 26 patients could not be assessed for either motor or sensory function, 6 could be assessed for motor function but not sensory, and 2 could be assessed for sensory function but not motor. 3 patients were documented as having abnormalities in both motor and sensory function. There were no isolated motor or isolated sensory abnormalities documented.

When examining the ulnar nerve for motor and sensory function, surgeons documented themselves as unable to fully assess the nerve for 41 patients. Of these 41 patients, 28 patients could not be assessed for either motor or sensory function, 6 could be assessed for motor function but not sensory, and 7 could be assessed for sensory function but not motor. 2 patients were documented as having abnormalities in both motor and sensory function. 1 patient had normal motor function and abnormal sensory function. 1 patient had documented abnormal sensory function, but could not be assessed for motor function. There were no patients with documented isolated sensory abnormality.

When examining the purely motor anterior interosseus nerve, surgeons documented themselves as unable to assess the nerve for 29 patients. 3 patients were documented as having abnormal motor function.

When examining vascular status, surgeons documented themselves as able to assess status via distal pulse or perfusion of hand in the affected limb for all 146 patients. 115 patients were documented as having both normal pulses and normal perfusion. 8 patients were documented as having normal pulses without explicit documentation of perfusion. 8 patients were documented as having normal perfusion without explicit documentation of pulses. 7 patients had documented normal perfusion with abnormal pulses. 2 patients had documented normal perfusion with documented absent pulse. 2 patients had documented normal perfusion

but could not be assessed for pulse status. 3 patients had abnormal perfusion and absent pulses. 1 patient was specifically documented as vascularly intact.

Statistical analysis revealed a significant correlation between patient age and ability of surgeons to obtain and document a complete neurovascular exam. The 104 patients from whom a complete exam could be obtained averaged 81.25 months of age, as compared to 48.88 months for patients from whom exam could not be obtained (Mean difference 32.369 months, $p=.0000073$, 95% CI 20.025-44.714). No significant correlations were found for BMI, where the 61 patients from whom exam could be obtained averaged 16.14 whereas the 23 patients from whom exam could not be obtained averaged 16.52 (Mean difference .379, $p=.608$, 95% CI -1.843-1.085). There was no significant correlation found between Hispanic ethnicity and ability of surgeons to obtain an exam (Pearson Chi-Square $p=.673$), or between Gender and ability of surgeons to obtain an exam (Pearson Chi-Square $p=.375$).

When examining the 123 patient subset of children with Supracondylar humerus fractures, there was no correlation found between Gartland fracture grade and ability of surgeons to obtain a preoperative neurovascular examination ($p=.222$, 95% CI -.307-.072).

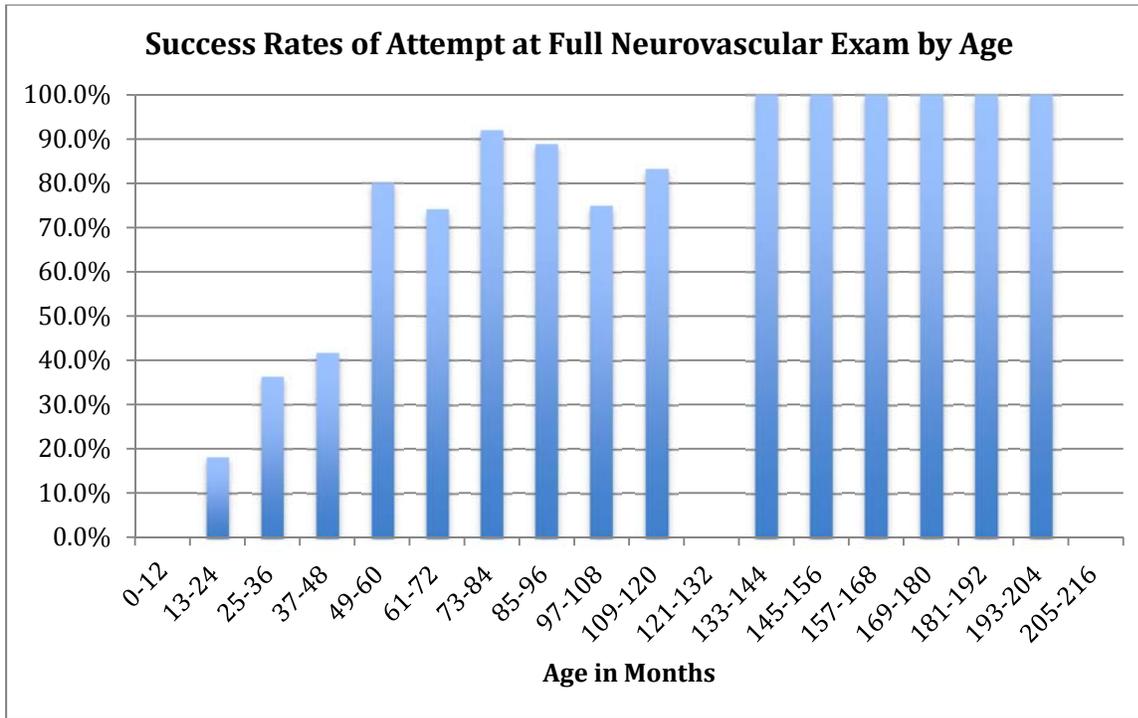
Table 1: Patient Characteristics

Study Sample	163 Subjects
Patients With Documented Attempt at Exam	89.6% (n=146)
Mean Age	5.9 years
Gender Distribution	
Male	48.6% (n=71)
Female	51.4% (n=75)
Ethnic Distribution	
Hispanic	47.3% (n=69)
Caucasian	38.4% (n=56)
Native American	7.5% (n=11)
African American	4.1% (n=6)
Asian	1.4% (n=2)
Other	1.4% (n=2)
Pre-Existing Medical Comorbidity	21.2% (n=31)
Prior Orthopedic Injury	5.5% (n=8)
Received Pain Medication Prior to Exam	95.6% (n=140)
Fracture Laterality	
Left	53.4% (n=78)
Right	46.6% (n=68)
Fracture Type	
Gartland Type II Supracondylar Humerus	40.0% (n=54)
Gartland Type III Supracondylar Humerus	47.3% (n=69)
Lateral Condyle	10.3% (n=15)
Medial Condyle	5.5% (n=8)
Concomitant Ipsilateral Radius Fracture	4.8% (n=7)
Method of Fixation	
Closed Reduction with Percutaneous Pinning	87.0% (n=127)
Open Reduction with Internal Fixation	10.3% (n=15)
Open Reduction with Percutaneous Pinning	2.7% (n=4)

Table 2: Surgeon Performance

Utilization of Elbow Specific H&P Form	93.2% (n=136)
Documentation of Complete Preoperative Neurovascular Exam	71.2% (n=104)
Nerve Specific Exam	
Median Nerve Fully Assessed	76.7% (n=112)
Radial Nerve Fully Assessed	76.7% (n=112)
Ulnar Nerve Fully Assessed	71.9% (n=105)
Anterior Interosseus Nerve Fully Assessed	80.1% (n=117)

Figure 1: Success Rates of Attempt at Full Neurovascular Exam by Age



	0-12	13-24	25-36	37-48	49-60	61-72	73-84	85-96	97-108
Number of Patients	1	11	11	12	21	27	25	9	12
Number of Successful Exams	0	2	4	5	17	20	23	8	9
Success Rate	0.0%	18.2%	36.4%	41.7%	80.1%	74.1%	92.0%	88.9%	75.0%

	109-120	121-132	133-144	145-156	157-168	169-180	181-192	193-204	205-216
Number of Patients	6	0	3	1	2	1	3	1	0
Number of Successful Exams	5	0	3	1	2	1	3	1	0
Success Rate	83.3%	N/A	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	N/A

Discussion

Despite recognition of the importance of pre-operative neurovascular examination in SCH fractures and widespread acknowledgement of the difficulty in performing such an assessment in pediatric patients, relatively little analysis has been done of the rate at which orthopaedic surgeons are able to thoroughly evaluate the pre-operative neurovascular status of pediatric patients with SCH fractures. A 2012 study conducted in the UK by Robertson et al²¹ assessed the emergency room documentation of neurologic status in pediatric patients with upper limb injuries. The study found documentation to be poor, with 94.2% of case notes containing no documentation of particular nerves examined, however its relevance is limited in that it evaluated ED personnel rather than trained pediatric orthopaedic surgeons. A second UK study in 2013 was conducted by Mayne et al⁷, this time looking specifically at pre-operative documentation by orthopaedic surgeons. The results of this study also showed insufficient documentation of neurovascular status, with only 8.8% of patients having complete preoperative neurological assessment documented and 13.9% of patients having complete vascular assessment documented.

Our study found much higher rates of documentation than either of the UK studies, with 89.6% of patients having documented attempt of neurovascular examination. Furthermore, our rates of successful full neurovascular examination, with specific documentation of particular nerves and perfusion status, were very high with 71.2% of attempted exams resulting in successful assessment. These rates may have been influenced by the implementation of an elbow specific H&P form, which was utilized in 93.2% of charts, although rates of successful examination and satisfactory documentation were also high in those charts where the form was not utilized. Rates of success may also be higher in our study as exams were performed by fellowship trained pediatric orthopaedic surgery attendings as opposed to general orthopedists and emergency physicians, with the additional training and experience specific to the orthopedic care of the pediatric population allowing for more accurate results in otherwise difficult patients.

Our study found the ulnar nerve to be the most difficult nerve to assess in patients with elbow fractures, followed by the median and radial nerves, with the anterior interosseus nerve being the easiest to successfully examine. This pattern runs opposite to the injury pattern described by Babal et al.⁵, but is expected as nerves which were conclusively injured would be marked as assessed within the framework of our study.

Analysis of correlations between patient demographics and inability to obtain complete exam revealed a statistically significant correlation between patient age and incomplete exam, with younger patients being less likely to have documentation of full neurovascular examination. Whereas attempted exams were successful in 71.2% of all patients, documentation of full neurovascular examination was only successful in 16.7% of patients younger than 24 months of age and 31.4% of patients younger than 48 months. Conversely, attempted examination was possible in 84.6% of patients older than 60 months. These results are consistent with expectations, as older children are more likely to be able to comply with commands in motor testing, and advanced verbal ability may aid in evaluation of sensory function. Additionally, older children may be more comfortable in the hospital setting and more willing to cooperate with clinicians. Three distinct age categories were identified, those being 0-48 months, 49-120 months, and greater than 121 months. These categories had documented success rates for complete neurovascular examination of 31.4%, 82.0%, and 100.0% respectively. The difference in success rates between the youngest group and middle group was found to be significant (Mean difference 50.6%, $p < 0.0001$, 95% CI 30.5254-66.7516), as was the difference in success rates between the youngest group and oldest group (Mean difference 68.6%, $p = 0.0001$, 95% CI 34.9743-83.1708). The difference in success rates between the middle group and oldest group was not found to be statistically significant (Mean difference = 18%, $p = .1259$, 95% CI -11.3313-26.9477). Lack of significance with this last comparison is likely due to the small sample size of the oldest age group.

We found no significant correlations with any other demographic factors, including fracture type or severity, BMI, gender or ethnicity. Of these, the lack of correlation with fracture severity was unexpected. We suspect that this may be due to lack of sample size, or due to the administration of pain medication prior to exam. Although we did attempt to

analyze whether patients received analgesic therapy, we did not look at the amount or type of medication received, and as such were unable to control for its effects.

Future Directions

While our study found significant results for age related factors in line with what would be expected, it was limited in terms of enrollment and sample size. Although Phoenix Children's Hospital is a large tertiary care center with a high volume, it may be advantageous to consider a multicenter trial to achieve greater power. Additionally, although our study looked at medication and analgesic administration prior to examination, it did so only in a yes/no fashion. A follow-up study analyzing pre-examination medication administration in terms of amount of analgesia provided may yield significant results and help to guide emergent management of these fractures.

Conclusion

Although a complete and detailed neurovascular examination is considered necessary when evaluating pediatric elbow fractures, it may not always be possible, especially with younger patients. Although fellowship trained pediatric orthopaedic surgeons were more successful in obtaining and documenting preoperative neurovascular examination than other clinicians, they were unable to fully assess a significant portion of patients. Over a fourth of our patients (29%) were unable to reliably participate in a full preoperative neurovascular exam. Younger children (less than 5 years of age) were less likely to participate in a complete neurovascular assessment. Neurovascular examinations in the setting of elbow fractures in children less than five years of age were unreliable and incomplete.

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