Original Clinical Article

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Management of paediatric humeral shaft fractures and associated nerve palsy

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Abstract

Purpose The aim of this study is to review the management of all paediatric humerus diaphyseal fractures treated at a single institution over a 20-year period.

Methods Retrospective review from between 1996 and 2016 identified 96 humerus shaft fractures in paediatric patients (0 to 17 years). After excluding those deceased from inciting trauma, pathological and perinatal fractures, 80 patients remained for analysis. Data collected included age, fracture type, displacement, nerve palsy, treatment, complications and time to union. Radiographs were reviewed at the time of injury and at latest follow-up.

Results Of 80 paediatric humeral diaphyseal fractures, 65 (81%) were treated with immobilization. In all, 15 (19%) fractures were treated with surgical stabilization. Most common indications were fracture displacement, open fractures and to improve mobilization in patients with multiple injuries. Fractures were stabilized with a plate (eight), flexible nails (five), external fixation (one) and percutaneous pinning (one). The operative group, compared with the nonoperative group, was older, had more high-energy mechanisms, more open fractures and increased fracture displacement. All patients in the nonoperative and operative groups went on to union with minimal complications. A nerve palsy was present in five patients (6%) with three of the five involving the radial nerve (4%). All nerve palsies were observed and had full neurological recovery.

Conclusion Over a 20-year period nonoperative management of paediatric humerus shaft fractures was successful in the majority of patients. Operative stabilization, when rarely indicated, had a low complication rate and improved radiographic alignment. All nerve injuries fully recovered without surgical intervention.

Level of evidence IV

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Introduction

Humeral shaft fractures are relatively uncommon in the paediatric population, estimated to comprise 0.4% to 3% of all paediatric fractures and 10% of all paediatric humerus fractures.[1-3] The vast majority of humerus shaft fractures in both paediatric and adult populations are treated nonoperatively with minimal complications.[2] Operative indications for humerus shaft fractures include open fractures, to improve mobilization in polytrauma patients, bilateral injuries, ipsilateral forearm fractures, a 'floating elbow' and compartment syndrome.[2] Benefits of surgical stabilization include earlier mobilization, often with almost immediate mobilization. The indications, fixation methods, complications and outcomes after operative stabilization of paediatric humerus shaft fractures have not been well documented in the literature.[4-7]

Adult humeral shaft fractures can be complicated by radial nerve palsy with an average incidence of 11.8%.[8] In contrast, there are no studies citing the incidence or management of radial nerve palsy among paediatric patients sustaining humeral shaft fractures. Current practice in the paediatric population is extrapolated from the adult literature, where debate regarding optimal management of radial nerve palsy continues. Advocates of early nerve exploration claim that acute surgery is technically easier and safer than a delayed procedure with fracture stabilization reducing further nerve damage risk from mobile bone ends.[8] Proponents of expectant observation note a high rate of spontaneous recovery and suggest that nerve recovery is similar with either early or late repair.[8] Given this limitation in the current literature, our study sought to evaluate incidence of nerve palsy in paediatric humeral shaft fractures and evaluate the results of expectant or operative management of nerve injury.

The aim of this study is to review the outcomes of paediatric patients treated for a humeral shaft fractures, both nonoperatively and operatively, and compare differences in patient demographics, injury mechanisms, fracture characteristics, nerve deficits, treatments and clinical and radiographic outcomes.

In this study, the term 'shaft' is used synonymously with 'diaphysis' and includes only those fractures found in the anatomical diaphyseal area of the humerus. It was felt that this review should be restricted to the diaphyseal area of the humerus given that fractures in the anatomic diaphysis of the humerus have very specific and unique fracture failure patterns.

Materials and methods

After institutional review board approval we performed a retrospective electronic chart review of a 20-year period (1996 to 2016) of paediatric patients treated for traumatic humerus shaft fractures at a Level 1 trauma centre (Mayo Clinic, Rochester, Minnesota). An initial search of an institutional trauma registry revealed 522 paediatric patients with 'humerus fractures', consisting of the proximal humerus (230, 44%), humeral shaft (96, 18%) and the distal humerus (196, 38%). We reviewed all 96 humerus shaft fractures in paediatric patients (age 0 to 17 years) during the study period. Excluded patients include eight which died from the inciting trauma, four patients with pathological fractures through unicameral bone cysts treated nonoperatively, three newborns with perinatal fractures treated nonoperatively and one patient who presented for flexible nail removal after stabilization at an outside hospital with no prior records or subsequent follow-up, leaving 80 patients for analysis.

Data collected included patient demographics, fracture characteristics, treatment, complications and outcomes. Fracture type was classified using the paediatric and adult Arbeitsgemeinschaft für Osteosynthesefragen (AO) classifications.[9-12] We elected to publish both the paediatric and adult classifications in the case that future comparative research might wish to include this cohort for meta-analyses or systematic review. Fracture and injury characteristics were recorded including open *versus* closed fractures, mechanism of injury, other injuries sustained, suspected abuse or trauma related and presence of nerve palsy.

Fracture management was recorded to include operative *versus* nonoperative management including length and type of immobilization. Radiographs were reviewed by two non-blinded observers (MAO, JAP). Initial radiographs were evaluated for fracture angulation, translation, shortening, location (proximal, middle, distal shaft) and AO classification. The latest follow-up radiographs were evaluated for union, degree of angulation, amount of shortening and translation. Complications were documented, including loss of reduction, refracture, nerve injury or symptomatic hardware requiring unplanned removal. Planned removal of hardware was not recorded as a complication.

Statistical analysis was performed using statistical software. Statistical significance was set at a p-value < 0.05. Continuous variables were evaluated with 2-sided *t*-test for parametric data and the Wilcoxon test for non-parametric data with means presented with SD, difference between means and the 95% confidence intervals (CIs). Categorical data was compared with the chi-square or Fisher exact tests.

Results

Demographics and fracture characteristics

Of the 80 paediatric humeral shaft fractures 53 (66%) were in male patients and the mean age was 10 years (SD 5; 0 to 17). The mean follow-up was 24 months (median 8; 1 to 183). Fractures in this series by AO adult classification were most commonly type 12A (n = 53) (Table 1). By

Table 1 Patients in series by Arbeitsgemeinschaft für Osteosynthesefragen (AO) adult fracture type

Fracture description		AO adult classification	Number in series	Extrapolated AO paediatric classification
Simple	Spiral	12A1	13	12-D/5.1
	Oblique	12A2	10	12-D/5.1
	Transverse	12A3	30	12-D/4.1
Wedge	Spiral wedge	12B1	3	12-D/5.2
	Bending wedge	12B2	3	12-D/5.2
	Fragmented	12B3	3	12-D/5.2
Complex	Spiral	12C1	0	12-D/5.2
	Segmental	12C2	0	12-D/4.2
	Irregular	12C3	1	12-D/5.2

AO paediatric classification, the most common was subtype 12-D/4.1 (n = 30) and 12-D/5.1 (n = 23) (Table 2). In all, 55% of injuries were considered high energy. Four fractures (5%) were attributed to abuse.

Fracture management

Surgical stabilization occurred in 15 (18%) patients, all of which were approaching skeletal maturity, with an mean age of 16 years (15 to 17). Details of each case are presented in Table 3. Indications in order of prevalence included fracture displacement/angulation (five), open fractures (four), patients with both fracture displacement/angulation and to improve mobilization due to multiple injuries (three), to improve mobilization in patient with multiple injuries (two) and a floating elbow (one) (Fig. 1). Fractures were definitively stabilized with open reduction and plate internal fixation (eight), flexible intramedullary nailing (five), external fixation (one) and closed reduction and percutaneous pinning (one). The five patients treated with flexible nailing underwent planned hardware removal.

In all, 65 (81%) patients were treated nonoperatively. The mean age of was ten years (3 to 14). Immobilization

Table 2 Patients in series by Arbeitsgemeinschaft für Osteosynthesefragen (AO) paediatric fracture type

Fracture description		AO paediatric classification	Number in series
Complete transverse (</= 30°)	Simple	12-D/4.1	30
	Multifragmentary	12-D/4.2	0
Complete oblique or spiral (>/= 30°)	Simple	12-D/5.1	23
	Multifragmentary	12-D/5.2	10

(a) **(b)** **(c)** **(d)**

Fig. 1 An 11-year-old male sustained open left humeral shaft fracture in high speed motocross injury and was taken acutely for irrigation and operative stabilization with flexible nail stabilization. Injury **(a, b)** and 12 months post-injury **(c, d)** radiographs show fracture healed in acceptable alignment.

Table 3 Case details of operatively fixed paediatric humerus shaft fractures

Age (yrs)	Sex	Mechanism	Indications	Fixation type	Nerve palsy	AO classification (adult paediatric)	Angulation	Shortening	Translation	Follow-up (mths)	Complications
17	F	MVA	Mobilization with fractured femur/tibia/ankle	ORIF	-	12A3 12-D/4.1	6	0.6	1.9	12	-
17	F	MVA	Displacement	ORIF	-	12A1 12-D/5.1	-	-	-	65	-
16	M	Auger injury	Open fracture and traumatic below elbow amputation	ORIF	-	12A3 12-D/4.1	-	-	-	5	-
17	F	ATV	Displacement and contralateral shoulder dislocation	ORIF	-	12A2 12-D/5.1	20	1.5	2	13	-
17	M	MVA	Displacement with sacrum and ipsilateral ankle fracture	ORIF	-	12A3 12-D/4.1	34	2.5	1.8	6	-
17	M	MVA	Mobilization with head injury, tracheostomy, open left knee injury	ORIF	-	12B3 12-D/5.2	10	0.9	0.6	11	-
16	M	MVA	Open comminuted fracture, ipsilateral femur fracture	ORIF	-	-	-	-	-	9	-
15	M	Motocross	Redisplacement after CRPP elsewhere	ORIF	-	12B1 12-D/5.2	17	1.4	1.7	8	Deep hardware infection
13	F	MVA	Mobilization with fractured femur	FN	-	12A3 12-D/4.1	8	0.7	1.9	3	-
14	M	Motocross	Ipsilateral both bone forearm fracture	FN	3/5 Ulnar nerve palsy	12A3 12-D/4.1	10	1.6	2.3	12	-
11	M	Motocross	Displacement	FN	-	12A3 12-D/4.1	19	1.9	1.6	12	-
3	F	ATV	Open fracture	FN	-	12A2 12-D/5.1	-	-	-	4	-
13	M	Go-cart	Displacement	FN	0/5 Median nerve palsy	12A3 12-D/4.1	33	2.1	21	14	-
8	F	ATV	Grossly contaminated open fracture	Ex fix	-	12A2 12-D/5.1	12	1	1.9	5	-
3	M	Fall from monkey bars	Unstable distal diaphyseal fracture only reducible with excessive elbow flexion	CRPP	-	-	-	-	-	2	-

MVA, motor vehicle accident; ATV, all-terrain vehicle; CRPP, closed reduction, percutaneous fixation; ORIF, open reduction internal fixation; FN, flexible intramedullary nails; Ex fix, external fixator strategies included a coaptation splint (29), a functional brace (19), a hanging arm cast (12), a sling (ten), pinning the arm to chest in infants (three) and a shoulder immobilizer (two). The majority of patients transitioned through various immobilization types during the study period. The patients managed with definitive nonoperative management were immobilized a mean of six weeks (3 to 18). A total of 72 patients were treated with nonoperative management initially, with seven converting to surgery (10%) due to loss of reduction. Due to patients passing through various stages of immobilization, we were unable to perform statistical analysis to determine whether a particular immobilization strategy was superior or inferior. Upon careful review of patients treated nonoperatively, no trends were noted when comparing immobilization type, fracture classification, age or sex on complications, outcomes or rate of conversion to surgical stabilization.

Table 4 compares the operative and nonoperative treatment groups, demonstrating no difference in sex, initial fracture angulation, nerve palsy, complications and time to heal. The operative group was older (13 years *versus* ten years; 95% CI 0.4 to 1.6; p = 0.01), had more high energy mechanisms (100% *versus* 44%; p = 0.004), open fractures (27% *versus* 2%; p = 0.04), fracture shortening (1.4 cm *versus* 0.8 cm; 95% CI 0.6 to 1.1; p=0.02), and fracture translation (1.8 cm *versus* 1 cm; 95% CI 0.1 to 1; p = 0.02).

All patients in this study went on to union with no subsequent procedures needed for delayed union or nonunions. At last follow-up there was less humerus angulation in the operative group (2° *versus* 9°; 95% CI -0.9 to -13; p = 0.02) and less translation (0 mm *versus* 0.5 mm; 95% CI -0.8 to -0.1; p = 0.007).

Complications

Four patients experienced complications (5%). Three patients treated nonoperatively experienced refracture at an mean of 12 weeks (9 to 15) after initial injury. All were treated conservatively with immobilization and ultimately went on to union without surgical intervention.

In the operative group a 15-year-old who was treated with closed reduction and percutaneous pinning of a distal diaphyseal fracture at an outside hospital presented two weeks postoperatively with loss of reduction and was managed with pin removal and open reduction internal fixation with plate and screws. Five weeks from the second procedure he developed a deep wound infection and underwent irrigation and debridement with retained hardware. One year after surgery, after the fracture was healed, he underwent removal of the hardware.

Nerve injury

Nerve palsy with a deficit in motor function was noted in five patients (6%). There were two radial nerve injuries presenting with complete motor loss, one ulnar nerve injury presenting with 3/5 motor function, one median nerve injury presenting with motor loss and one mixed radial, ulnar and median nerve injury presenting with motor loss. Overall, the radial nerve palsy incidence was 4% (3/80). All nerve injuries occurred in closed fractures. Two underwent closed reduction and flexible nailing without exploration of the nerve while the remaining three were treated nonoperatively (Fig. 2). Patients with nerve palsy did not differ in terms of age, sex, open fracture, AO paediatric or adult classification, fracture angulation

Table 4 Comparison of operative versus nonoperative treatment groups

	Surgical stabilization (n = 15)	n	Nonoperative (n = 65)	n	Mean difference	95% confidence interval	p-value*
Mean age, yrs	13 SD 5	-	10 SD 5	-	3	1 to 6	****0.01**
Sex, % male	*60*	-	*67*	-		-	0.5
High energy trauma, %	*100*	-	*44*	-		-	****0.004**
Open, n (%)	4 (*27*)	-	1 (*2*)	-		-	****0.004**
Mean fracture angulation	16° SD 10°	10	14° SD 11°	42	3	-5 to 11	0.4
Mean fracture shortening, cm	1.4 SD 0.6	10	0.8 SD 0.8	41	0.6	0.6 to 1.1	****0.02**
Mean fracture translation, cm	1.8 SD 0.5	10	1 SD 0.8	18	0.7	0.1 to 1	****0.02**
Nerve palsy, n (%)	2 (*13*)	-	3 (*5*)	-	-	-	0.2
Complications, n (%)	1 (*6*)	-	3 (*5*)	-	-	-	0.5
Mean time to heal (weeks)	15 SD 9	7	11 SD 5	26	4	-2 to 10	0.1
Mean final angulation	2° SD 4°	12	9° SD 10°	36	-7	-0.9 to -13	****0.02**
Final shortening, cm	0	12	1.2 SD 5	35	-1.2	-4 to 2	0.4
Final translation, cm	0	12	0.5 SD 0.5	15	-0.5	-08 to -0.1	****0.007**

*see methods and materials section for definition of statistical analysis used
**statistical significance set at a p-value < 0.05.

or shortening or fracture location (Table 5). Fracture translation was higher in the nerve injury group (2 cm *versus* 1.1 cm; 95% CI 0.1 to 1.8; p = 0.02). Full nerve recovery was noted in all patients at an mean of 154 days (2 to 378). Mean time to onset of recovery was 41 days (0.25 to 120). The median and ulnar nerve palsies recovered faster with an mean onset of recovery of one day (0.25 to 2) and full recovery at three days (2 to 4).

Discussion

Of the studied population, traumatic humeral shaft fractures made up 18% (96/522) of all paediatric humerus fractures at our institution, a slightly higher percentage than previously reported.[3] High energy mechanisms were responsible for the majority of fractures with many patients presenting with multiple fractures. The inciting trauma resulted in death in eight (8%) patients and four (4%) patients were victims of confirmed abuse, highlighting the need for a detailed examination and workup of paediatric patients presenting with these fractures.[2,13]

The majority of paediatric patients over this 20-year time span were successfully treated nonoperatively with minimal complications. Three nonoperatively-treated patients had refractures during the healing process but eventually healed with continued observation. For the minority of patients who underwent operative fracture stabilization, the most common indication for surgery was fracture displacement and/or angulation with or without multiple injuries in patients approaching skeletal maturity. One patient in the operative group experienced a complication with loss of reduction after closed pinning requiring formal open reduction and internal fixation, which was further complicated by a deep infection requiring multiple operations and long-term intravenous antibiotics.

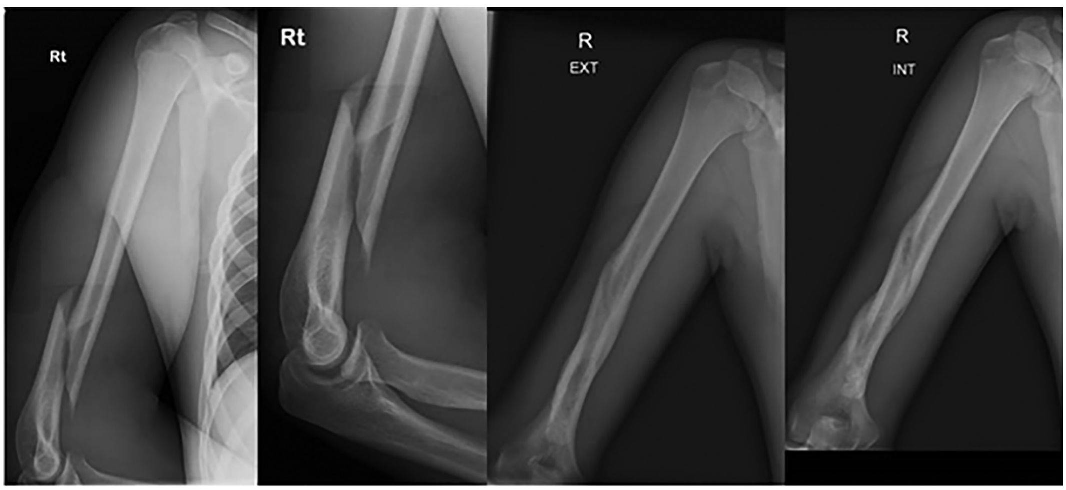

Fig. 2 A 16-year-old male sustained closed right humeral shaft fracture in a high-speed dirt bike injury with associated radial nerve palsy which resolved in three weeks. Injury radiographs and six months post-injury films show fracture healed in acceptable alignment.

Table 5 Comparison of patient characteristics with and without nerve palsy

	Nerve palsy (5)	n	Nerve intact (75)	n	Mean difference	95% confidence interval	p-value*
Mean age, yrs	12 SD 2	-	10 SD 5	-	2	-2 to 7	0.3
Sex, n (%)	3 (*60*)	-	50 (*66*)	-	-	-	1
Open, n (%)	0	-	5 (*6*)	-	-	-	1
Surgically stabilized, n (%)	2 (*40*)	-	13 (*17*)	-	-	-	0.2
Mean fracture angulation	20° SD 8°	5	14° SD 11°	47	6	-4 to 17	0.2
Mean fracture shortening, cm	1.3 SD 0.5	5	0.8 SD 0.8	46	0.4	-0.3 to 1	0.2
Mean fracture translation, cm	2 SD 0.3	5	1.1 SD 0.3	25	0.9	0.1 to 1.8	****0.02**
Fracture location, n (%)	-	5	-	58	-	-	0.04
Proximal	0 (*0*)	-	4 (*6*)	-	-	-	-
Middle	4 (*80*)	-	42 (*72*)	-	-	-	-
Distal	1 (*20*)	-	12 (*20*)	-	-	-	-

*see methods and materials section for definition of statistical analysis used
**statistical significance set at a p-value < 0.05

Canavese et al[14] recently compared 36 skeletally immature patients (age range, six to 16 years) who underwent nonoperative (n = 10) *versus* external fixation (n = 11) or flexible intramedullary nailing (n = 15) and found no difference in clinical outcomes with all patients regaining full range of movement and function of the upper extremity. All fractures healed with similar numbers in each treatment group experiencing secondary displacement. The operative group experienced two refractures, one operative infection and one ulnar nerve injury compared with none in the nonoperative group. These outcomes are similar to what we observed in our patient population. Nonoperative treatment, when able, results in excellent outcomes but when necessary operative treatment is successful with minimal complications.

Discussion of humeral shaft fractures in the paediatric population would be incomplete without mentioning the so-called 'relative indications' that surgeons face in practice. These include desire for return to sport, athletics or hobby; desire by patient or family for earlier mobilization; strong familial preference; complex family and/or socioeconomic situations; and concern for family noncompliance among others. Our cohort did not find any of these relative indications documented or discussed in the medical record, nor did we find any discussion of this related to humeral diaphysis fractures in the published literature.

This study's finding can be of use when counselling paediatric patients presenting with humeral shaft fractures. The majority of paediatric humerus shaft fractures can and should be treated nonoperatively, however, operative reduction, when indicated, results in reliable healing, improves alignment and has a low complication rate in our series. Considering that a majority of paediatric humerus shaft fractures will heal uneventfully without surgery, strict adherence to operative indications is prudent as the complications of surgery can be severe.

The most common indication for surgery in this study was fracture displacement/angulation severity, however, angulation in this group ranged from 6° to 34° and shortening ranged from 6 mm to 25 mm. Some authors have recommended treating diaphyseal fractures with > 15° of angulation, however, in adults 30° of angulation and 3 cm of shortening can be accepted with minimal functional deficits.[2,14,15] The acceptable degree of paediatric humerus shaft deformity is unlikely to be less than that of their adult counterparts and there is no consensus on any exact parameters for operative stabilization.

The age of our operatively treated patients was significantly older than the entire cohort, at 13 years *versus* 10 years (p = 0.01). This is likely due to the fact that surgeons may treat patients who are close to or past skeletal maturity similarly to adults. These patients may also be involved in higher risk behaviour and have high energy mechanisms. However, our small study numbers preclude making any conclusive findings.

Radial nerve injury after humeral shaft fractures has received much attention in the adult population, with incidence noted at up to 12%.[8] In our study, 6% of patients presented with a nerve palsy. Four of the five patients had complete motor loss and one presented with 3/5 motor strength. All recovered full function with observation. Recent meta-analysis of adult radial nerve palsy among humeral shaft fractures found an 88% rate of recovery with spontaneous recovery of 71% in patients treated conservatively.[8] In the meta-analysis, average time to onset of recovery was seven weeks and time to full recovery of six months. Our series saw slightly better results with an average onset of recovery of six weeks and full recovery of five months. This information is helpful in counselling patients that present with complete motor loss after humerus shaft fracture supporting extended observation of these injuries. No patients developed nerve palsy after operative stabilization. A prior study examining 25 paediatric patients treated with external fixators or flexible nails did report one ulnar nerve injury after external fixation so this remains a risk of operative stabilization.[14]

Management of nerve injuries associated with humeral shaft fracture is debated. Some advocate for exploration of the nerve in distal third fractures of the humeral shaft in the adult population (Holstein-Lewis fracture).[16] In our series, 13 patients had distal third, Holstein-Lewis fracture pattern, with only one of these experiencing nerve palsy. Most nerve palsies in this study were associated with fractures in the middle third of the humerus. By AO classification, four were adult type 12A3 and one 12A2. By paediatric subtype, four were type 12-D/4.1 and one 12-D/5.1. There seemed to be a trend towards nerve injury occurring in the transverse type fractures by both paediatric (12-D/4.1) and adult classification (12A3), however, the numbers in this series are too low to reach significance. This may be an area of interest for future studies to determine whether transverse type fractures may be related to higher incidence of nerve damage in the paediatric population.

Some surgeons argue that nerve palsy which develops after fracture closed manipulation and splinting should warrant surgical exploration, given that this could be a sign of acute nerve entrapment between fracture fragments. No patients in our series developed a nerve palsy after fracture manipulation. Fracture translation was significantly associated with nerve palsy in this cohort, with translation of 2 cm in the palsy cohort. Direction of displacement did not correlate. This suggests that amount of fracture translation should be a clue to nerve injury.

Nerve injuries in humeral shaft fractures which fail to recover pose a particularly challenging problem. Questions include whether electro-diagnostic studies or imaging modalities such as magnetic resonance imaging or ultrasound should be obtained, and, if so, at what time frame. A recent meta-analysis by Shao et al[8] attempted to comment on optimal wait time and imaging studies, however, no conclusive evidence could be declared. Their article found a 4.3-month average wait period before surgical exploration in the adult population. The article also suggests that four months was the most common time before advanced imaging was obtained; however, this was based on limited data. All nerve injuries in our series were associated with closed fractures and all palsies fully recovered with observation suggesting that this is a safe course to take in a paediatric humeral shaft fracture.

This study is limited by retrospective nature. Directly comparing operative and nonoperatively treated groups is limited by differences in age, injury severity and coexisting injuries. We also do not report on any functional outcomes. The radiographic observers were not blinded, presenting a source of bias to the radiographic measurements.

This study demonstrated that a majority of children with humeral shaft fractures treated nonoperatively healed with few issues. When indicated, operative reduction provided a safe alternative to immobilization in paediatric patients approaching skeletal maturity with few complications and improved radiographic alignment. All patients with nerve palsies regained complete function at an average of five months with no surgical exploration needed.

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ETHICAL STATEMENT

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Was obtained from all individual participants included in the study.

ICMJE CONFLICT OF INTEREST STATEMENT

TAM reports educational consultancy to Orthopediatrics, a stockholding in Viking scientific, and is a Course Director for Broadwater, all outside the submitted work.
All other authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

MAO: Chart review/data collection, manuscript preparation, Review.
JAP: Manuscript preparation and review.
HL: Chart review/data collection.
AAS: Manuscript preparation and review.
ANL: Manuscript preparation and review.
TAM: Manuscript preparation and review.

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