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Review Article

Elastic stable intramedullary nailing of humerus fractures in children

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Abstract: Humerus fractures are infrequent in children, except for supracondylar humerus fractures. Historically, most of the humerus fractures in children and adolescents have been treated non-operatively based on the tremendous remodeling potential of the proximal humeral physis and the great arc of shoulder motion. However, in older patients, less-than-anatomic reduction may lead to prolonged pain and restricted shoulder mobility and expose the gleno-humeral joint and rotator cuff to higher stress with unknown long-term effects. Elastic stable intramedullary nailing (ESIN) had encountered slower acceptance as a standard of treatment for humeral fractures than for any other long bone in pediatric patients. A retrospective analysis of 32 patients aged 5.5-17.8 years who were treated with ESIN for humeral fractures was performed. The most common cause of injury was fall, followed by traffic accidents. There were 16 proximal, 12 shaft and 4 distal humeral fractures. Twenty-five patients had isolated fractures, while 7 had polytrauma. Most of the patients underwent surgery within 24 hours after injury. Closed reduction of the fracture was achieved in 23 patients. The nails were inserted in a retrograde direction in 28 patients (22 from the lateral and medial sides, 6 only from the lateral side) and in an anterograde direction in 4. The mean duration of surgery was 83.13 min. No major complications were observed. All fractures healed without delayed unions or non-unions. Nail protrusion was encountered in 3 patients, skin irritation in 1 and difficult extraction in 2 patients. The average duration of follow up was 1.2 years. ESIN is a reliable method of treatment for displaced humeral fractures in children and adolescents. Once the patient is under general anesthesia and in the operating theatre for the reduction of humeral fracture, stabilization with ESIN is a better option than any type of plaster immobilization.

Keywords: ESIN, humerus, proximal, shaft, distal, fracture, children, operative, complications.

Introduction

Humerus fractures are relatively uncommon in childhood except for supracondylar humerus fractures. Proximal humeral fractures (PHF) and humeral shaft fractures (HSF) each account for 1-3% of all fractures in children [1-3]. Fractures of the proximal humeral epiphysis comprise 4-7% of all epiphyseal fractures [4]. Fractures of the distal humerus are the most common humeral fracture in children [5]. The majority of these fractures are supracondylar humeral fractures, which account for approximately 17% of pediatric fractures and more than 50% of elbow fractures in that age group [6]. A small subset of distal humerus fractures-fractures above the olecranon fossa on the metaphyseal-diaphyseal junction-occurs in less than 3% of displaced distal humeral fractures [7]. These rare fractures may be particularly difficult in terms of obtaining and maintaining stable reduction.

Historically, most humerus fractures in children and adolescents have been treated non-operatively. Operative treatment was reserved for open fractures, polytrauma patients, “floating elbow” injuries with ipsilateral humerus and forearm fractures, bilateral humerus fractures and humerus fractures associated with lower extremity fractures to facilitate mobilization and weight bearing with the support of crutches. This conservative treatment approach was based on the tremendous remodeling potential of the proximal humeral physis, which is responsible for more than 80% of overall humeral growth, and on the enormous arc of shoulder motion, which is unparalleled in the

human body. Growth from the proximal physeal plate would be capable of correcting a large amount of initial fracture displacement, and the mobility of the gleno-humeral joint would compensate for possible residual malunion. However, many of the studies reporting the outcomes of non-operative treatment of proximal humeral fractures focused on non-adolescent pediatric patients [8, 9]. Moreover, other studies showed excellent results for the operative treatment of those fractures in older patients [10]. Additionally, while remodeling of 100% displacement and up to 60° of angulation in any plane have been reported [11] in younger patients with proximal humeral fractures, Dameron and Reibel [8] reported that corrections of less than 20° may be expected in children older than 11 years. Furthermore, Bahrs et al [10] reported impediments to anatomical reduction, such as the interposition of periosteum and entrapment of the long tendon of the biceps in more than 50% of adolescent patients treated operatively for proximal humerus fractures. In a systematic literature review, Pahlavan et al [12] concluded that patients below age 10 years and above 13 years should be treated as a distinct group. In the older patients, who have a limited remaining growth period, the remodeling potential is decreased. Less than anatomic reduction in such patients may lead to prolonged pain and restricted shoulder mobility. This restriction combined with increased physical requirements, mostly due to higher demands in sports activities, may expose the gleno-humeral joint and rotator cuff to higher stress and unknown long-term effects [11]. Humeral shaft fractures have less remodeling capacity than proximal fractures because the distance from the potent proximal physis is greater. Nevertheless, many of those fractures can be treated conservatively using functional bracing, splints or hanging casts if the angulation is less than 20° [13]. Again, higher physical demands and, moreover, the unacceptable and disturbing cosmetic appearance of an angulated upper arm [14], socioeconomics aspect and comfort represent relative indications [15] for anatomic reduction and fixation of humeral shaft fractures in older children. The preferred method of fixation for both proximal and shaft humerus fractures is ESIN. Finally, distal humerus fractures have limited remodeling potential because of the weak distal humeral growth plate. The slow growth of the distal humerus has very little capability to correct angular malalignment. This has resulted in the development of strong, straightforward recommendations for the treatment of frequent supracondylar humerus fractures. Debate may exist regarding whether percutaneous fixation with Kirschner wires or ESIN is a better option. Few reports of rare fractures of the distal metaphyseal-diaphyseal junction (DMDJ) just proximal to the olecranon fossa have been published [6, 7]. These fractures may be difficult to reduce and even more difficult to stabilize.

The aim of our study is to analyze the indications, treatment results and complications of ESIN for humerus fractures in children at a single university pediatric center.

Materials and methods

We performed a retrospective review of the hospital records of pediatric patients who were treated surgically for humerus fractures from January 2010 to December 2016. The inclusion criteria were fractures of the proximal humerus, including shaft and distal humerus fractures, treated with ESIN. The exclusion criteria were supracondylar humerus fractures; humerus fractures stabilized with percutaneous Kirschner wires, external fixators or plates and screws; and fractures treated non-operatively. The patients' gender, age at the time of accident, mechanism of injury, concomitant injuries, fracture pattern, whether the fracture was open or closed, neurovascular status, involved side and previous treatment (if any) were recorded. The patients were admitted through the emergency service of our hospital or were referred from regional secondary centers either as emergencies or after failed initial treatment. After clinical examination, AP and lateral x-rays were obtained for all patients. The interval from injury to ESIN was also recorded. We prefer to treat all fractures as soon as possible, preferably within 24 hours of the injury. Data regarding the method of reduction, nail entry point, diameter and type of nails used (titanium or stainless steel) and operative time were obtained from the patients' operative charts.

Operative technique

We followed established principles for the ESIN operative technique [16] for humerus fractures.

The patients were placed in dorsal decubitus on a radiolucent table with arm extension. Under general anesthesia, the shoulder and entire arm were prepared and draped. Under image intensifier control, closed reduction of the fracture was attempted. In cases of satisfactory reduction, we proceeded to nail insertion. If reduction of the fracture could not be achieved after several attempts, open reduction was performed immediately. For proximal fractures, we utilized a standard delto-pectoral approach, while for shaft and distal humerus fractures, a lateral approach was preferred. Nails were inserted in an anterograde or retrograde fashion. For proximal and shaft fractures, retrograde nail entry was used, while for fractures in the distal third of the humerus, an anterograde insertion technique was utilized. The nail diameter was determined as 40% of the diameter of the medullary canal at its narrowest point. Two nails of equal size were selected and pre-contoured. When pre-bending the nails, care was taken to ensure that the apex of the curve matched the fracture site. If both nails were inserted in a retrograde direction from the lateral side, a 3-4 cm long incision starting approximately 1 cm proximal to the tip of the lateral epicondyle was made. The incision was extended down to the periosteum, and the soft tissue was protected with small retractors. The cortex was then carefully perforated with an awl. We did not use a drill bit for this purpose. The first perforation was made in the proximal end of the incision, and the second was made approximately 1-2 cm distally and 1 cm medially from first one. The nails were then advanced with slight rotational movements. The total arc of rotation should not exceed 90 degrees to prevent the nails from twisting around one another (the so-called cork-screw phenomenon). In some cases, it was difficult or impossible to insert the nails in a rotational manner, and they could only be advanced with gentle blows from a slotted hammer. In cases when nails must cross physeal cartilage, they should be advanced only with gentle hammering. In these specific cases, we found that using nails with sharp points was helpful. If one nail was inserted from the lateral side and the other from the medial side in a retrograde fashion, the lateral incision was similar to that previously described but was shorter, usually 2 cm in length. A medial incision was made approximately 1 cm proximal from the tip of the medial epicondyle and extended to the periosteum. The ulnar nerve was protected with small retractors during dissection and cortex perforation with an awl. For anterograde nail configurations, an incision was made laterally at the level of the distal insertion of the deltoid muscle. Soft tissues were dissected sharply down to the periosteum, and 2 perforations of the cortex were made with an awl. Placing entry points too distally may jeopardize the radial nerve and compromise the stability of the fixation. The positions of the fracture fragments and nails were verified with intraoperative x-rays. After insertion, the nails were cut and anchored in the metaphyseal bone by light blowing over beveled impactor. Wound(s) were then sutured. Immobilization with a splint or sling was applied in some cases to control pain and discomfort.

Follow-up

Postoperative X-rays were obtained one day after surgery. Patients with isolated fractures were usually discharged on the day following surgery, and only patients living in very distant areas were discharged on the second or third postoperative day. The discharge of polytrauma patients was dictated by their other, more severe injuries. Patients were scheduled for evaluation 7-10 days postoperatively, when the sutures were removed. X-rays were obtained to detect potential nail migration or secondary displacement of fragments. Any complications were noted and treated accordingly. X-ray control was performed 4 and 12 weeks post-surgery to monitor fracture consolidation and union. The nails were removed after 6-12 months. If osteosynthesis of multiple fractures had been performed in patients with polytrauma, we attempted to remove all the hardware in one procedure after all the fractures had healed. Patients were followed clinically for a year after nail extraction, but X-rays were not routinely obtained at follow-up visits.

Statistical analysis

The collected data were entered into an MS Office Excel spreadsheet for further processing. Continuous variables are expressed as the means ± SD (standard deviation). Categorical variables were expressed as simple values and percentages. Two-tailed T-test assuming unequal variances (Welch test) was used

Table 1. Patient demographics, fracture characteristics and treatment

Patient No.	Sex	Age (y)	Side	†Cause of accident	Fracture location	‡Indication for surgery	Reduction	§Nail Insertion	Nail diameter (mm)	Time to operation	Duration of operation (min)	Time to removal (d)	Length of hospitalization (d)	Follow-up (y)
1	M	5.9	R	MVA	Proximal	PT	Closed	RLM	2	<24 h	90	276	9	1.4
2	M	13.7	L	MVA	Proximal	PT	Closed	RLM	3	<24 h	120	245	10	1.7
3	F	10.9	R	FSH	Proximal	PD	Closed	RLM	2	<24 h	60	184	2	1.6
4	M	14.8	L	FSH	Proximal	PD	Closed	RLM	3	<24 h	70	178	2	1.7
5	M	11.4	R	FSH	Proximal	PD	Closed	RLM	2.5	<24 h	85	134	1	1.6
6	M	12.7	R	FSH	Proximal	PD	Closed	RLL	3	<24 h	120	195	2	1.7
7	M	11.6	L	FSH	Shaft	PD	Closed	RLL	2.5	<24 h	90	283	1	1.8
8	M	11.3	L	SCH	Shaft	OF	open	RLM	3	<24 h	60	131	2	1.3
9	F	14.8	R	MVA	Shaft	PT	Closed	RLL	2.5	12 days	60	361	14	1.9
10	F	11.8	R	SCH	Proximal	SD	Closed	RLM	2.5	12 days	75	162	5	1.3
11	M	16.9	L	MVA	Shaft	PT	Open	RLM	3	<24 h	30	161	7	1.5
12	M	7.4	R	FH	Shaft	PF	Closed	RLM	2.5	<24 h	150	207	4	0.6
13	M	17.8	R	FSH	Shaft	PF	Closed	ANT	2.5	<24 h	120	67	3	1.14
14	F	6.2	L	FSH	Distal	SD	Open	ANT	1.8	3 days	105	38	5	1.2
15	M	11.8	L	FH	Proximal	PD	Closed	RLM	2.2	<24 h	65	126	3	1.1
16	F	8.6	L	FSH	Shaft	SD	Closed	RLL	2	8 days	65	150	4	1.0
17	M	16.1	L	FSH	Proximal	PD	Open	RLM	2.5	<24 h	45	223	2	1.0
18	M	12.5	R	SPI	Shaft	PD	Closed	RLM	3	<24 h	85	241	2	0.7
19	M	9.0	L	FSH	Distal	SD	Closed	ANT	2.5	10 days	45	129	5	0.4
20	M	14.9	L	MVA	Shaft	PT	Closed	RLM	2.5	<24 h	65	308	24	0.9
21	F	10.1	R	FSH	Distal	PD	Open	ANT	2.5	<24 h	135	221	1	1.5
22	M	16.8	R	SPI	Shaft	PF	Open	RLM	3	<24 h	120	197	3	1.5
23	F	9.6	R	FSH	Proximal	PD	Closed	RLM	2	<24 h	70	191	1	1.5
24	F	13.3	R	FSH	Proximal	PD	Closed	RLL	2.5	>24 h	85	179	2	0.79
25	M	9.2	R	FB	Proximal	PD	Open	RLL	2.5	<24 h	30	153	1	1.2
26	M	11.3	L	SCH	Shaft	OF	Open	RLM	2.2	<24 h	60	131	2	1.2
27	M	12.4	R	SPI	Proximal	PD	Open	RLM	3	<24 h	60	127	7	1.2
28	M	17.3	L	FB	Shaft	PD	Open	RLM	2.5	<24 h	125	/	5	1.2
29	M	5.6	R	MVA	Proximal	PD	Closed	RLM	2	<24 h	80	119	7	1.5
30	M	12.9	R	FSH	Proximal	PD	Closed	RLM	2.5	<24 h	80	233	2	0.55
31	M	11.5	R	MVA	Proximal	PD	Closed	RLM	2.5	<24 h	90	192	6	0.1
32	M	10.6	L	FB	Shaft	OF	open	RLM	3	3 days	120	/	7	1.4

†*Cause of accident:* MVA-motor vehicle accident; FSH–fall from standing height; SCH-school-related fall; FH-fall from height >1 m; SPI-sports injury; FB-fall from bicycle. ‡*Mechanism of injury:* PT-polytrauma; PD-primary displacement; OF-open fracture; PF-pathologic fracture; SD- secondary displacement. §*Nail insertion*: RLM–retrograde lateral and medial insertion; RLL-retrograde, both nails lateral; ANT-anterograde.

Table 2. Fracture characteristics in different anatomic parts of the humerus

	Anatomical region of humerus			
	Proximal*,§	Shaft§,†	Distal*,†	Total
No. of patients	16	12	4	32
Mean age (years ± SD)	12.17±2.43	12.60±4.10	8.75±1.74	11.90±3.26
Gender				
Male	12	10	2	24
Female	4	2	2	8
Side				
Left	4	7	3	14
Right	12	5	1	18
Other injuries				32
Isolated	12	9	4	25
Polytrauma	3	3	0	6

*p<0.05; §p>0.05; †p>0.05.

for comparisons, and p values ≤ 0.05 were considered statically significant. MedCalc® statistical software version 9.5.2.0 was used for statistical analysis.

Results

Thirty-two pediatric patients (24 male, 8 female) met the inclusion criteria. The mean age at time of injury was 11.90±3.26 years (range 5.64-17.79). The age of the patients was biased to some extent by the fact that during the first 4 years of the study, we treated patients up to 15 years old, while in the following 3 years, patients up to 18 years were treated because of changes in health care regulations. There were 18 right-sided and 14 left-sided injuries. A detailed overview of the patients' demographics and fracture characteristics is provided in **Table 1**. Sixteen patients had fractures of the proximal humerus, 12 had fractures of the shaft, and 4 had fractures of the distal humerus. The patients with distal humerus fracture were significantly younger than the patients with shaft and proximal humerus fractures (p<0.05), while the age difference between the patients with shaft and proximal humerus fractures was not significant (p>0.05; **Table 2**). Twenty-two patients were injured by falls: 14 in falls from ground level, 2 in falls from heights greater than 1 m, 3 in falls during sports activities and 3 after falls from a bicycle in non-traffic accidents. Seven patients were injured in traffic accidents: 4 as pedestrians struck by a car, 2 as passengers in car collisions and one as a bicyclist hit by a truck. Twenty-six patients had isolated fractures, while 6 had polytrauma. All the polytrauma patients were injured in traffic accidents. The most common indication for operation was primary displacement (**Table 3**). Three patients had grade II open fractures according to the classification of Gustillo and Anderson. Twenty-five patients underwent surgery within 24 hours after injury. This means that the children were operated on either on the day of the injury or the next morning if they had been injured and admitted late in the night. The remaining 7 patients underwent surgery 3-12 days post injury. Three patients were operated on after 3 days because of a loss of reduction on x-ray control. Three children were admitted 8 days after injury because of failed conservative treatment at other institutions. They underwent surgery within 2-4 days after admission. Finally, one girl underwent surgery 12 days after injury, when she had recovered from an emergent neurosurgical operation.

Closed reduction was performed in 23 cases and open reduction in 9. In the group of patients who underwent open reduction, 3 had open fractures, 1 had a pathologic shaft fracture, 2 had distal humerus fractures, 1 had a shaft fracture with radial nerve paresis, 1 had a proximal epiphysiolysis and 1 had a proximal metaphyseal fracture with a periosteal strip that prevented reduction. For ESIN of the fractures in our series, 32 pairs of nails were used. The diameter of the nails was 2.0, 2.5 or 3.0 mm, but the two nails used for a single patient were always of the same diameter. Titanium elastic nails (TEN) were used in 24 patients, and stainless steel nails (SEN) were used in 8 patients. The majority of the fractures (22 patients) were stabilized by nails inserted in a retrograde fashion, one from the lateral side and one from the medial side (**Figure 1**). In 6 patients, both retrograde nails were inserted laterally (**Figure 2**), and in 4 patients, the nails were placed in an anterograde direction (**Figure 3**). No intraoperative or immediate postoperative complications were observed.

Table 3. Overview of the treatment of humeral fractures

	Anatomic site of humerus fracture			
	Proximal	Shaft	Distal	Total
Indications for surgery				
Primary displacement	13	3	2	18
Secondary displacement	1	1	2	4
Polytrauma	2	3	0	5
Open fracture	0	3	0	3
Pathologic fracture	0	2	0	2
Time from injury to surgery				
<24 h	14	9	2	25
>24 h	2	3	2	7
Type of reduction				
Closed	14	7	2	23
Open	2	5	2	9
Type of nails				
Titanium	12	9	3	24
Steel	4	3	1	8
Nail insertion site				
Retrograde-lateral and medial	12	9	1	22
Retrograde, both nails lateral	4	2		6
Anterograde	0	1	3	4
Time to nail removal (d ± SD)	194±54.82	180±79.84	140±80.82	183±66.88
Length of hospitalization (d)				
Primary operation	4.81	5.17	3	4.72
Nail removal	1.44	0.92	2	1.38
Isolated fractures	3.07	3.56	3.0	3.08§
Polytrauma	17.0	11.50	0.0	11.83§
Follow-up (y)	1.24±0.50	1.12±0.52	1.14±0.52	1.22±0.45

§p<0.05.

The duration of the procedure from the induction of anesthesia to transfer to the recovery room was 83.13±30.57 min; range from 30-150 min (**Table 4**). There was no statistically significant difference in the duration of procedure between open and closed fractures (p>0.05), isolated fractures or fractures in polytrauma patients (p>0.05) or among fractures in different segments of the humerus (p>0.05). The difference in the duration of procedure between the two surgeons who performed most of the surgeries was marked but statistically insignificant (mean operative time 75.59 vs. 106.43 min; p<0.05).

The overall length of hospitalization was 4.72±4.66 days. Children with isolated fractures had a significantly shorter length of stay (3±1.87 days) compared with polytrauma patients (11.4±6.49 days; p<0.05). The management of humerus fracture in children with polytrauma was never a reason for prolonged hospitalization. In 3 patients, the protrusion of nails through the head of the humerus was verified on X-ray control after 7-10 days. These patients were admitted, and under general anesthesia and fluoroscopic control, the position of the protruding nails was corrected the following day. All fractures were healed by the 12- to 14-week visit. There were no delayed unions and non-unions. One girl, aged 6.24 years old, with a distal humerus fracture and anterograde nail insertion had skin irritation from a protruding nail but no skin perforation at the 4-week visit. As X-rays showed consolidation of the fracture, we decided to remove the nails 38 days after insertion.

Shaft fractures in two boys were pathological, through a cystic bone lesion. Patients were 16.79 and 17.79 years old, and both had fractures of the right humerus. Open reduction of the fracture and cyst biopsy were performed in one patient. The fractures were stabilized with a pair of 3-mm nails inserted in an anterograde manner in one patient and in a retrograde manner in the other patient. After the complete healing of the fractures, both defects were only partially ossified. Open curettage was performed after nail removal. The defects were then filled with osteoconductive granules of β-tricalcium phosphate (ChronOS™).

We routinely recommend nail removal for all patients. The procedure is usually scheduled during school vacations. The nails were re-

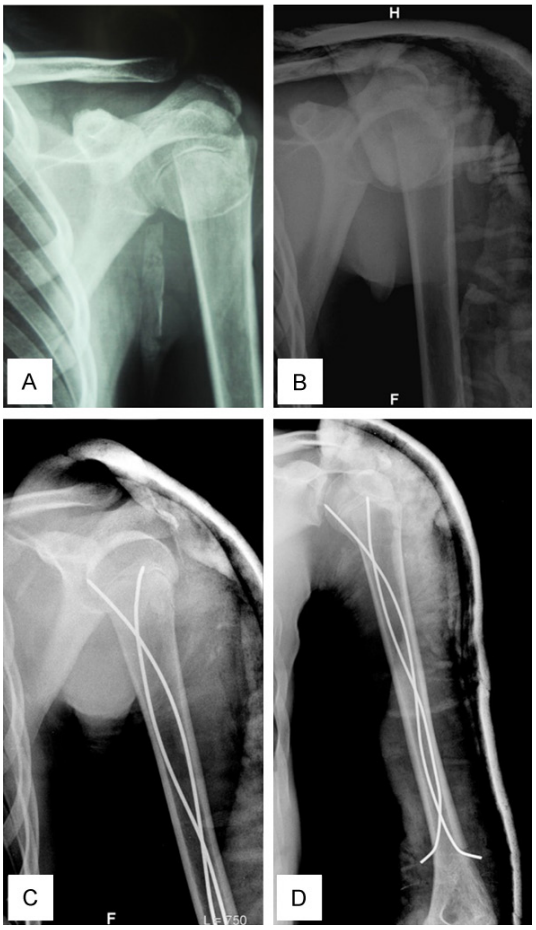

Figure 1. Lateral and medial nail insertion for retrograde ESIN; A. Isolated displaced proximal humeral fracture (patient No. 17); B. After attempted closed reduction; C and D. Retrograde ESIN through lateral and medial entry points.

moved in 30 patients after 183±66.88 days (range 38-361) or 26±9.55 weeks (range 5.43-51.57). The duration of hospitalization for nail extraction was 1.38±0.91 days. Most of the patients were discharged on the same day or the day after procedure; however, two patients who required the removal of multiple hardware were hospitalized for 4 and 5 days. Difficulties with nail removal were experienced in 2 patients.

The patients were followed for a mean of 1.12±0.45 years (range 0.15-1.92 years). The final follow-up visit was scheduled one year after nail extraction. Twenty-seven patients had full range of motion and had returned to all previous activities at their last follow-up visit, including 2 patients with pathologic fractures. Three patients with polytrauma had full range of shoulder and elbow motion but some limitations in activities as consequence of concomitant head, pelvis or femur injuries. Finally, 2 treated patients whose nails had not yet been removed had regained full range of motion but had restriction in sports activities.

Discussion

Fractures of the proximal humerus, shaft and distal metaphyseal-diaphyseal fractures are relatively rare in the pediatric population, and indications for non-operative or operative treatment are not well established [11, 12] compared with the far more common supracondylar humerus fractures. Although supracondylar humerus fractures can be successfully treated with ESIN [14, 15], many surgeons still prefer pinning with Kirschner wires because they consider ESIN unnecessarily complicated for this indication [17]. At our institution, displaced supracondylar humerus fractures are treated with reduction (closed or open) and percutaneous Kirschner wire fixation [18]. Therefore, patients with supracondylar humerus fractures were not included in our present study.

Thirty-two patients with humerus factures were treated with ESIN and were included in the study. The most common cause of injury was fall from standing height at home or on the playground. In a study conducted at 4 major children's hospitals, Knorr et al reported a similar distribution of causes of humerus fractures in children [14]. The mean age of the patients in our study (11.90 years) is comparable to the ages of patients in other reports [19-21]. The patients with distal metaphyseal-diaphyseal junction fractures were significantly younger than the patients with shaft and proximal humeral fractures. The average age of this subset of children (8.75 years) was younger than that of the patients in the study by Marengo et al [22] but older than patients in the studies by Fayssoux et al [6] and Ge et al [7]. The patients in the study by Knorr [14] were also younger than our patients, but their study also included patients with supracondylar humerus fracture. A strong male predominance was observed in the children with proximal and shaft fractures in our group of patients, in contrast to other series in which only a slight predominance of either gender was noted [14, 19, 20, 22]. This discrepancy may be explained by the higher activity levels of boys, as all the

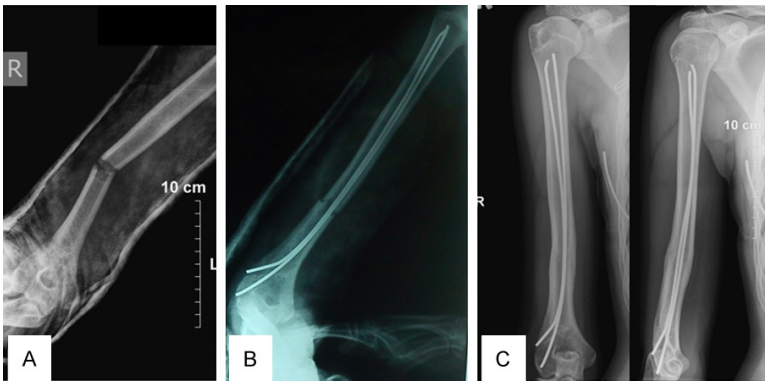

Figure 2. Retrograde ESIN with dual lateral nail insertion; A. Angulated shaft fracture in polytrauma patient (patient No. 9); B. Retrograde ESIN, both nails inserted from the lateral side; C. Healed fracture before nail removal, 52 weeks after index operation.

Figure 3. Anterograde ESIN; A. Distal humeral fracture; B. Varus angulation of 16°; C, D. Anterograde ESIN; E, F. 31 weeks after injury, before hardware removal.

patients who were injured in sports activities and bicycle-related falls were males. Furthermore, 5 of the 6 polytrauma patients were also males. The side of involvement was almost equal among our cases and in most published reports, with slight predominance of one or the other side. However, we could not explain the great proportion of right-sided fractures of the proximal humerus (3:1) in our patients, which is in contrast to the findings of other studies [19, 20, 23, 24].

Most of the patients (78%) underwent surgery within 24 h after injury, on day 0 (the day of injury) or day 1 (the day following the injury). In the multicenter study of Knorr et al, 85% of patients underwent surgery on the day of injury or the next day [14]. For patients admitted late at night whose operation could not start until well after midnight for any reason, we assumed that it was safe to postpone surgery for several hours providing that the patient had adequate immobilization, analgesia and monitoring. Of the 7 patients who underwent surgery more than 24 hours post-injury, 6 had a failed attempt of conservative treatment of their fractures (2 proximal, 2 shaft and 2 distal). The last patient was transferred from the neurosurgery department and underwent surgery 12 days after injury. We do not attempt closed reductions in the emergency setting. All reductions are performed under general anesthesia or conscious sedation in an operating theatre under fluoroscopic control. Moreover, we follow the basic rule of pediatric traumatology that reduction and definitive stabilization of displaced fractures must be performed in one sitting [25]. Thus, if closed reduction is impossible, immediate open reduction and fracture fixation is performed; if reduc-

Table 4. Operation time and duration of surgery in relation to type of reduction, type of injury, anatomic location of the humerus fracture and surgeons who performed operation

		Reduction*		Type of injury§		Part of humerus†			Surgeon‡	
	Total	Closed	Open	Isolated	Polytrauma	Proximal	Shaft	Distal	A	B
Aver.	83.13	79.57	92.22	85.19	74.17	76.25	90.42	88.75	75.59	106.43
Min	30	30	45	30	30	30	30	45	120	150
Max	150	150	135	150	120	120	150	135	30	60
S.D.	30.58	28.60	35.28	30.84	30.40	23.56	36.27	39.45	31.19	33.38

*p>0.05; §p>0.05; ‡p>0.05; ‡p>0.05.

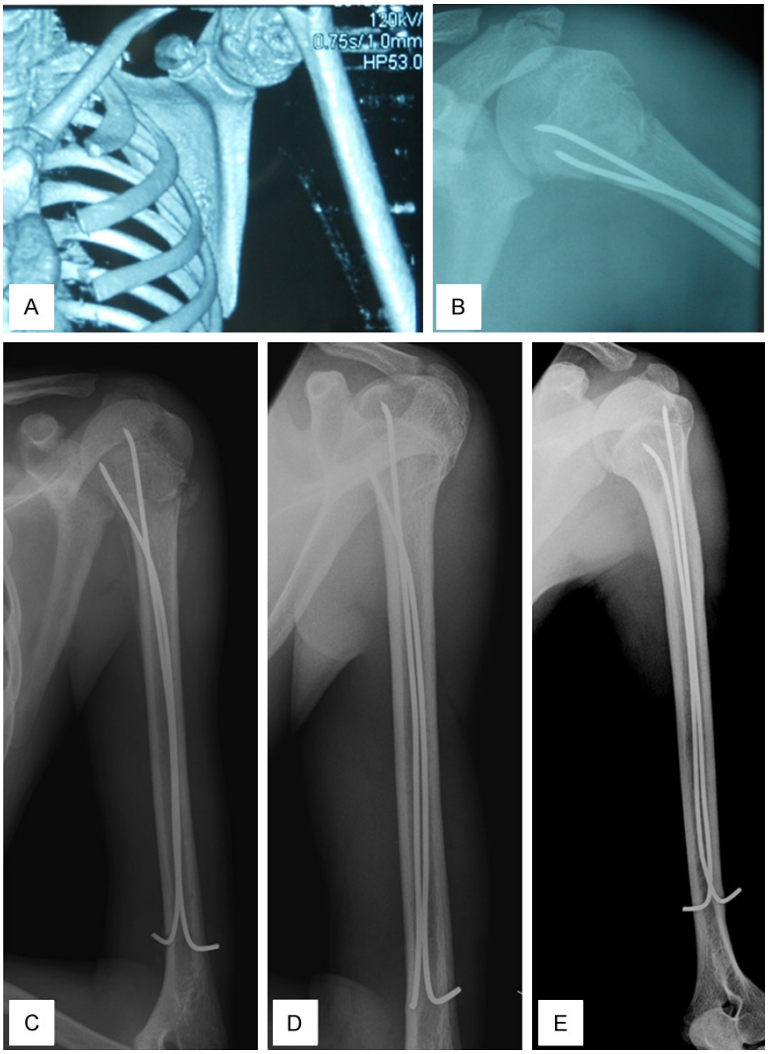

Figure 4. Retrograde ESIN with sharp-ended nails; A. CT scan with 3-D reconstruction of displaced proximal humeral fracture in a polytrauma patient (patient No. 20); B. 2 sharp nails were inserted in a retrograde direction; C. Consolidation of the fracture after 4 weeks; D, E. Healed fracture before nail extraction, 44 weeks post-injury.

tion cannot be maintained after a successful closed maneuver, the fracture is stabilized with ESIN. The average duration of operation was 83.13 minutes. The operation time was recorded from the induction of general anesthesia until transfer from the operating room to the recovery room. This is comparable to the 89 minutes reported by Kraus et al [20] but longer than the duration of surgery in other reports [7, 19, 26] (41.9 min, 54 and 74 min; respectively). In the study by Knorr [14], the operation time varied between 12 and 300 min. Generally, operation time depends on the characteristics of the fracture and the experience of the surgeon. As expected, the duration of the procedure in our study was longer for open than for closed reduction but was unexpectedly shorter for polytrauma patients than for patients with isolated injury. The average length of hospitalization of 4.72 days was similar to the length of stay reported in other series [7, 14, 19, 20]. The hospital stay was significantly shorter for patients with isolated fractures (3.08 days) compared with patients with polytrauma (11.83 days), whose length of stay was dictated by the severity of concomitant injuries. The mean duration of hospitalization for nail removal was 1.4 days (range 1-5 days), similar to that reported in previously studies.

The most commonly used nail diameter was 2.5 mm. In 5 patients with proximal humeral fractures, we used stainless steel nails with sharp points (**Figure 4**). We assume that sharp-

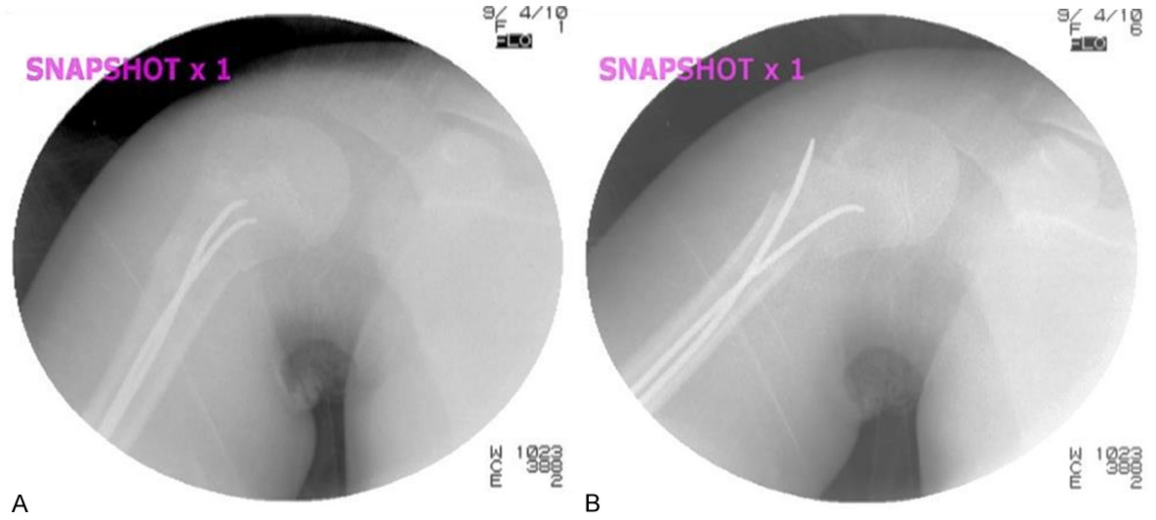

Figure 5. Snapshots of intraoperative fluoroscopy; A. On AP view, both nails appear to be inserted correctly in the proximal fragment; B. Lateral view demonstrates the misplacement of one nail through the fracture site.

pointed stainless steel nails have better purchase in the head of humerus and produce less damage to the growth plate during penetration compared with blunt-ended nails. Blunt-tipped nails may push the proximal fragment instead of penetrating it; thus, the use of sharp-tipped nails was proposed for proximal humeral fractures [27]. Of course, additional care must be taken to avoid perforation of the humeral head and penetration of the shoulder joint, which is much easier with sharp-pointed nails. The slow advancement of nails using multiple fluoroscopic controls in both AP and lateral projection is mandatory until the final impaction of sharp nails to prevent misplacement (**Figure 5**). Retrograde nail insertion using lateral and medial entry points was performed in nearly 70% of our cases. This configuration provides better balance of elastic forces and better fracture stability. If care is taken during dissection down the periosteum and good visualization, gentle retraction and soft tissue protection are ensured, the risk of both ulnar and radial nerve damage is minimal. The minimal complication rate that we observed with crossed pin fixation of supracondylar humerus fractures [18] has been of great support. The insertion of both nails from the lateral side through a separate hole may be indicated for proximal humeral fractures [15, 27, 28] as the crossing of nails at the fracture site is not essential for the stability of this type of fracture. Some surgeons have used this configuration even for diaphyseal fractures to minimize the risk of ulnar nerve damage. We used it in 6 of the reported cases (19%). Finally, anterograde insertion from the lateral side was used in 4 patients (3 distal fractures and 1 shaft fracture) as recommended in the literature [14, 15, 28]. The main indication for surgery in our patients was primary displacement, followed by polytrauma. Nevertheless, many patients had more than one indication for surgery [14].

Fractures of the proximal humerus

Proximal humeral fractures in children and adolescents have traditionally been treated conservatively. Many reports recommend nonoperative treatment because of the tremendous remodeling potential of the proximal humeral physis and the great ability of adjacent joints to compensate for possible residual malunions [12]. The main objections to those reports are the small number of older patients with displaced fractures and the higher proportions of younger children and patients with minimally displaced fractures. Furthermore, the reported results for the conservative treatment of severely displaced proximal humerus fractures in adolescents have shown worse results [11]. Indications for the operative treatment of proximal humerus fractures are expanding. Pahlavan et al [12] proposed the stratification of patients based on age: children <10 years should be primarily treated by closed means, those >13 years with displaced fractures should be offered the option of operative

treatment; and children in the interim group (aged 10-13 years old) should be treated on a case-by-case basis. Beaty [1] suggested that the indication for operative treatment should be based not only on stratification by age but also on the severity of displacement. We operated on 16 patients with this type of fracture with an average age of 12.17 years. Most of the patients (9) were 10-13 years old. Two patients were younger than 10 years (5.64 and 9.23 years); both had completely displaced fractures with significant shortening and angulation. There were no open fractures in this group. Three patients had polytrauma. Closed reduction could be achieved in all but 2 patients. One had proximal epiphysiolysis, and the other had a metaphyseal fracture with interposed periosteum. Although some authors [19, 29] have described one nail technique for the fixation of proximal humerus fractures, we have always used the standard ESIN technique [15, 16, 27, 28] with a pair of elastic nails of equal diameter. Surprisingly, our mean operative time for proximal humeral fractures (75.25 min) was shorter than the mean duration of operation for fractures of the shaft (90.42 min) and the distal humerus (88.75 min). However, difference in the mean duration of operation among surgeons supports Knorr's observation that ascending ESIN for proximal humerus fractures is not an operation for beginners [14]. We observed several complications. The protrusion of nails through the humeral head occurred in 2 patients. Both patients were scheduled for operation, and under general anesthesia, the position of the protruding nails was corrected. Nail extraction was difficult in 1 patient as the nails were initially cut too short. Two fractures healed with <10° of varus angulation. One patient complained of the appearance of scars at the lateral and medial entry points. Scar excision was performed at the time of nail extraction. Similar complications were reported in other published works [14, 19, 27, 28]. At the final follow-up visit, all the patients had range of motion and muscle strength that were comparable to uninjured side and were free of pain. Fifteen patients returned to the full spectrum of activities in which they participated before injury. One patient had limited physical activities at the last follow-up (after 44.71 weeks) as a consequence of pelvic, femoral and tibial fractures sustained during polytrauma.

After closed or open reduction, displaced proximal humeral fractures may be successfully pinned with Kirschner wires [11, 20, 30] or stabilized using ESIN [15, 19, 26-28]. Although excellent results may be achieved with either method, comparative studies have shown the advantages of ESIN [20] because the operation time is shorter, fixation is stable with no need for additional immobilization, and early mobilization is possible as there is no muscle transfixation. Moreover, we agree with Lefevre [27] that once a child with a displaced proximal humeral fracture is in the operating room under general anesthesia and is undergoing fracture reduction, stabilization of the fracture with ESIN is more appropriate than the application of a thoraco-brachial cast or any other type of cast.

Humerus shaft fractures

Diaphyseal humerus fractures have limited remodeling potential due to greater distance from the potent proximal humeral physis. Spontaneous correction of angular displacement >20° in younger patients and >10° in older children should not be expected, and displacement in any direction that exceeds these limits should not be accepted [14]. Nevertheless, most shaft fractures may still be treated conservatively. The main indication for surgery is polytrauma; in such cases, surgery is warranted to facilitate early mobilization or improve nursing in patients with concomitant head injuries and the inability to maintain reduction within acceptable limits [13, 31]. Most of our patients (75%) were older than 10 years with a mean of 12.60 years, which is comparable to the age reported in other studies [13, 21, 31]. Falls from minor heights during school or leisure activities, traffic accidents and sports- and bicycle-related injuries were the main mechanisms of injury in our patients, as previously reported by others [14, 21, 31]. Indication for ESIN was polytrauma in 3 patients (25%), open fractures in another 3, pathologic fractures in 2 (17%) and inability to obtain or maintain acceptable closed reduction in remaining 4 patients. Ten patients (83%) were operated on within 24 hours from injury. Open reduction was performed in 3 patients with open fractures and in one patient with a pathologic fracture. In the last case, we wanted to obtain biopsy material for histology. In the remaining 8

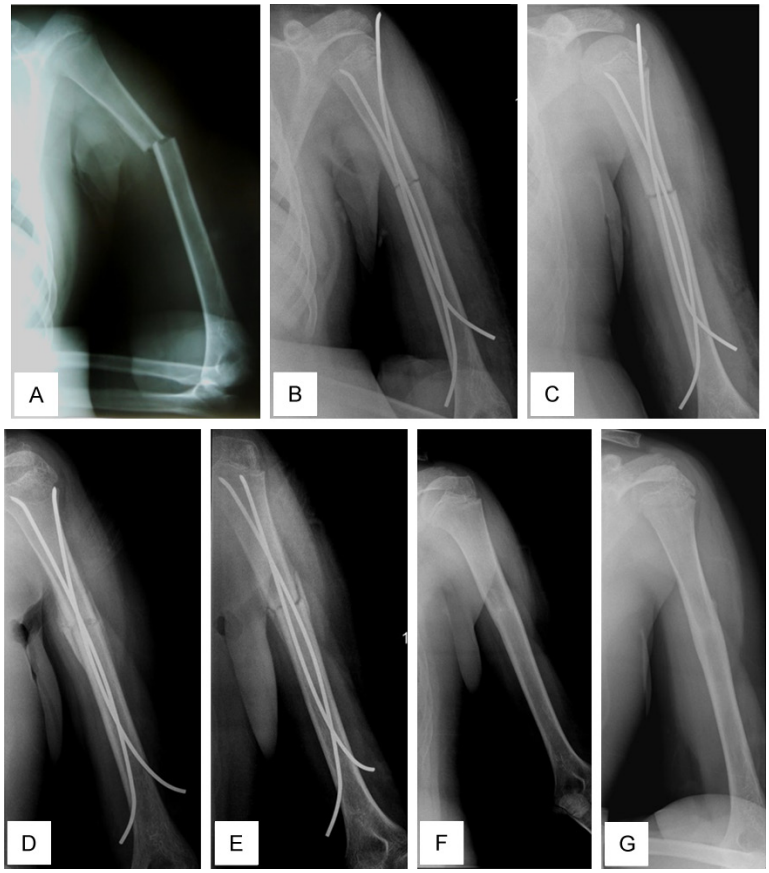

Figure 6. Proximal protrusion of lateral nail; A. Angulated shaft fracture; B, C. Proximal end of lateral nail protruded laterally on x-ray control after 7 days; D, E. Consolidation of the fracture without loss of reduction after nail correction; F, G. Healed fracture on most recent follow up (1.25 years).

patients, reduction was achieved by closed means. Nine pairs of titanium nails and 3 pairs of stainless steel nails were inserted. The preferred configuration in our study was retrograde insertion from the lateral and medial side, which was performed in 9 patients (75%). We believe that the bilateral insertion technique provides better biomechanical stability, as already stressed [25]. We did not experience the postoperative neurological complications reported by others [25]. One patient had transient radial nerve neuropraxia, which was recorded preoperatively. The dual lateral ascending technique preferred by Garg [13] and Maruthi [31] was used in 2 patients, and the descending configuration was used for only 1. Unexpectedly, the average operation time (90.42 min) for these patients was longer than that for proximal and distal humeral fractures. Nail protrusion was observed in one patient (**Figure 6**). Although the protrusion was lateral and there was no penetration of the articular surface, we decided to correct the nail position under general anesthesia. Finally, in one patient, the nails were removed with difficulty because one nail had been deformed as a consequence of a difficult insertion (**Figure 7**). All the fractures united uneventfully. At the last follow-up visit, all the patients had full range of shoulder and elbow motion that was symmetrical to the opposite side. Ten patients resumed their previous activity levels, while 2 polytrauma patients, one with head injury and other with multiple vertebral fractures, had physical and sports activity limitations that were unrelated to the humeral fracture.

Distal metaphyseal-diaphyseal junction fractures

Fractures of the distal metaphyseal-diaphyseal junction are rare, and their treatment may be problematic. Fayssoux et al [6] reported that oblique fractures may be difficult to reduce, and transverse fractures may be difficult to stabilize. We treated 4 patients with this type of fracture. The nails were inserted anterograde in 3 patients and retrograde in one. While Kelly [28] and Marengo [22] proposed descending nail insertion, Ge et al [7] used retrograde insertion through the lateral and medial epicondyle and concluded that this configuration may hold the distal fragment more firmly than anterograde nail placement or Kirschner wires. Two patients underwent surgery within 24 h of injury, and the remaining 2 patients underwent surgery after 3 and 10 days, respectively. One six-year old girl experienced irritation at the insertion site but without skin perforation. As her fracture was consolidated on x-rays, the nails were removed after 38 days. No other complications were observed. In a recent study of 14 patients treated for displaced distal humeral fractures, Marengo found that ESIN resulted in stable reduction, good rotational control, and faster mobilization [22]. In another recent report, Ge

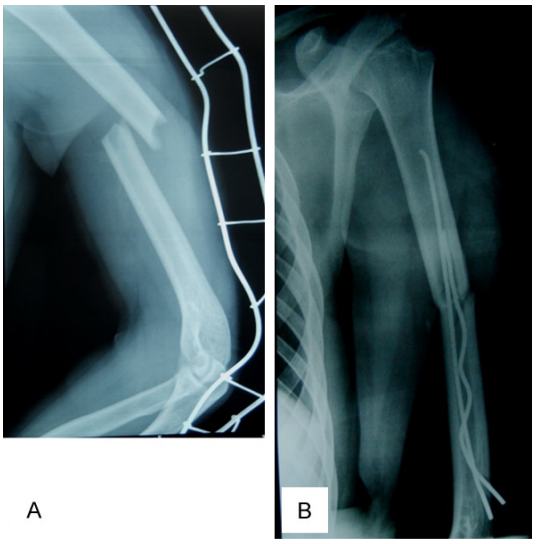

Figure 7. Deformation of nail due to difficult insertion; A. Displaced mid-shaft humerus fracture; B. As a result of insertion difficulties, one nail was markedly deformed. Consequently, extraction was difficult.

compared the treatment results of 39 patients with either percutaneous Kirschner wire fixation or ESIN and concluded that ESIN appeared superior to Kirschner wire fixation, providing shorter operation time, less surgical blood loss and shorter healing times for distal humerus fractures [7]. Although our experiences in the treatment of distal humeral fracture with ESIN are limited by the small number of patients, our treatment results are comparable to results of other researchers.

Finally, we did not use ESIN to treat any patient with displaced supracondylar humerus fractures, although excellent results for such treatment have been described [14, 28, 32].

Conclusion

Proximal humeral fractures in children older than 13 years with displacement of more than 50% of the shaft diameter and angulation >20° should be anatomically reduced under general anesthesia and stabilized. Whenever reduction cannot be obtained by closed means, open reduction should be performed because an obstacle may exist. ESIN has clear advantages over Kirschner wire fixation because it offers greater stability of fixation, no need for additional immobilization and earlier mobilization of patients. In children older than 10 years, indications for surgery should be established on an individual basis taking in account the amount of displacement and the remaining potential for growth. In pediatric patients younger than 10 years, surgery is seldom indicated in cases of polytrauma, open or pathologic fractures and fractures with marked displacement that cannot be reduced.

Displaced diaphyseal humerus fractures are best stabilized with ESIN. Displacement of >10° in any plane should not be tolerated. Polytrauma patients and those with pathologic fractures will benefit from ESIN regardless of the amount of displacement. The choice between retrograde and anterograde nail insertion is driven by fracture location and pattern. Ascending insertion from the lateral only or from lateral and medial entry points both have advantages and drawbacks. The utilization of one or another configuration should be based on fracture characteristics rather than the surgeon' preference.

Distal humerus fractures on the diaphyseal-metaphyseal junction may be difficult to reduce and stabilize. ESIN, applied in either an anterograde or retrograde fashion, is a reliable method for treating these infrequent fractures.

Once a pediatric patient is under general anesthesia in the operation room for the reduction of a displaced humeral fracture, regardless of its anatomical location, we would consider ESIN a better option than any type of cast immobilization.

Closed reduction and percutaneous pinning is still the preferred method of treatment for supracondylar humerus fractures despite growing published evidence of excellent results for the treatment of those fractures with ESIN. Thus, ESIN should be considered as a possible method of treatment for displaced supracondylar humerus fractures.

Disclosure of conflict of interest

None.

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