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Outcomes and complications of Titanium elastic nailing for forearm bones fracture in children: our experience in a district general hospital in the United Kingdom

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Intramedullary Titanium elastic nailing (TENS) is successfully used for irreducible and displaced forearm bone fractures in children. The purpose of this study was to report the potential complications and functional outcomes associated with paediatric forearm fractures treated with TENS nails. We retrospectively reviewed 65 children with displaced forearm bone fractures treated by TENS nailing with a mean follow-up of 5.84 months (4-12). Data detailing patient demographics, fracture characteristics, associated fractures, injury surgery interval, grade of the operating surgeon, methods of fixation, time to union, the timing of removal of the nail, and complications were collected and analysed. The mean age in our study was 9.13 years. 92% had fractures of both radius and ulna, 83.3% had fixation of both bones, and 16.7% had single bone fixation only. Open reduction was required in 38.5% of cases. The average time to fracture union was 10.34 weeks (6-20). The average time of implant removal was 20.12 weeks (9-32). We observed an overall complication rate of 41.5%. We noted a higher (56% vs 32.5%, *p=0.059*) complication rate in open reduction cases. According to the Price criteria, we had excellent to good results in over 98% of patients despite a slightly higher complication rate. Titanium elastic nailing is a safe, reliable method of internal fixation for irreducible or unstable fractures of both bones of the forearm in children. Open reduction of fracture was associated with higher complications. Despite higher overall complications, we noted excellent functional results in most cases.

Keywords: Titanium elastic nailing, forearm bone fracture, children, outcome & complications.

INTRODUCTION

Forearm fractures are common injuries in children, accounting for approximately 3-5% of all fractures and 30% of the fractures in the upper extremity[1]. Treatment with closed reduction and cast immobilisation is still the gold standard for most paediatric forearm fractures[2]. Previous studies have shown that the failure of nonoperative treatment of midshaft fractures in the paediatric population ranges between 39 and 64%[3]. Acceptable angulation before surgical intervention varies with age and fracture location. In children younger than 10 years, the perfect anatomical reduction is not necessary because of greater remodelling potential; in older than 10 years, near anatomical reduction is essential to preserve a full range of forearm motion[4]. In children with at least two years of growth remaining, greater angulation after closed reduction is acceptable. For these patients, the upper limits in the coronal and sagittal planes include 20 degrees in the distal third, 15 degrees in the middle third, and 10 degrees in the proximal third[5]. Recently, there has been an increasing trend towards operative treatment to avoid the complications associated with nonoperative treatment, including malunion, loss of reduction and limited forearm rotation[6]. The operative indications include open fractures, failure to obtain or maintain adequate closed reduction, compartment syndrome, floating elbow and displaced fracture in older children nearing skeletal maturity[7]. Use of Intramedullary nails or plate & screws are options for forearm fracture fixation, with both methods of stabilisation being similarly effective[8]. Intramedullary fixation with Titanium elastic nails (TENS) has emerged as the most common method for the fixation of forearm fractures in skeletally immature patients.

The study aimed to assess the clinical and radiographic outcome and potential complications associated with fractures of the forearm bones treated with titanium elastic nails in children.

MATERIAL &METHODS

We retrospectively reviewed all children (1-14 years) treated with Titanium elastic nailing for fractures of the forearm bones between January 2013 and June 2021. A total of 71 children were treated during this period. Patients with inadequate medical records, imaging or clinical follow-up, those with hybrid fixation (plate and nailing), and pathological fractures were excluded from the study. 65 children were available to be included in the current study.

The study variables included patient demographics, mechanism and type of injury, associated fractures, pre-operative neurovascular injury, any prior fractures in the same forearm bone, injury to surgery interval, operating surgeon, operative reports, time to union, timing of removal of metalwork and duration of follow up. Operative fixation was used when we could not obtain or maintain acceptable reduction by closed means, loss of reduction after initial Manipulation and plaster, grossly displaced fractures, and open fractures. Radiographs were reviewed for fracture characteristics: fractured bone (radius, ulna, or both), fracture location, and fracture type (open or closed), the pattern of fracture (transverse, oblique or comminuted). Intraoperative variables included the grade of the surgeon, surgical technique & method of fixation, type of reduction (open or closed), use of tourniquet, duration of surgery and size of nail used etc.

Following complications were noted and recorded: infection, re-fracture, delayed union, malunion, non-union, tendon rupture, nerve injury, implant migration through the skin, loss of reduction, and loss of functional range of motion.

No radiological bony consolidation at 12 weeks was considered as delayed union, and no consolidation at 6 months was considered as non-union.

Outcomes of forearm rotation at the final follow-up were classified using the criteria by Price et al.[4]. Price criteria are widely used in the literature to assess the functional outcome of fractures of the bones of the forearm in children.

Fisher's exact was used to assess whether there was a statistically significant difference in complication between the open and closed reduction. A p-value of < 0.05 was considered statistically significant.

All the patients were operated under a general anaesthetic. The patients were placed supine position with the upper limb on a radiolucent side table. Which bone to be fixed first was decided by the surgeon. The entry point for radius 1-2 cm is proximal to the lateral aspect of the radial physis and was identified by fluoroscopy. Care was taken not to injure the extensor tendons and superficial radial cutaneous nerve. The entry hole was created using an awl. The nail was prebent to achieve intramedullary three-point fixation. Under image intensifier guidance, a closed reduction of the radius was performed, and the nail was advanced in a smooth oscillating movement in a retrograde fashion past the fracture site to achieve fixation. The entry point for the fixation of the ulna was over proximal metaphysis with antegrade advancement of the nail past the fracture site. The diameter of the nails ranged between 1.5mm and 3 mm, depending on the child's age and the size of the bone, taking care to ensure that the diameter of the nail filled at least 50% of the inner diameter of the diaphysis and nail did not pass the epiphysis. When closed reduction could not be achieved, a small incision was used to reduce the fracture openly, and the nails were introduced by the same method described previously. The number of attempts at closed reduction before resorting to open reduction was at the discretion of the operating surgeon. In our series, we had instances where only the radius or ulna was fixed using the nail. This decision was taken by the operating surgeon after clinical and radiographic evaluation of adequate reduction and stability of the fractures. The surgeon checked the free range of motion of the elbow, wrist and forearm for all fractures at the end of the operation, and intraoperative radiograph was taken.

The cut end was buried under the skin in all cases. The skin incisions were sutured using an absorbable suture subcuticular fashion. Postoperatively, most were treated in the above elbow cast for 6 weeks (based on radiographic findings during follow-up). Nail removal was scheduled (4-6 months from surgery) when radio-graphic four cortices healing was ensured (Figure 1).

RESULTS

A total of 71 patients who had fractures of both bones of the forearm were included in the study, with 65 meeting the inclusion criteria. Detailed demographics and fracture characteristics are shown in Table I. There were 40 (61.5%) males and 25 (38.5%) females in the group. The mean age of the patients was 9.1 years (range: 4-14 years); The fractures were on the right forearm in 31(47.7%) and left in 34 (52.3%). The average weight of the children was 32.62 kg (range:17-66 kg). 63 (97%) patients had closed fractures, and 2 (3%) had a type I open fracture. The fracture was comminuted in 4 (6.2%) cases. A total of 60 (92.3%) children had fractures of both radius and ulna, 3 (4.6%) had radius

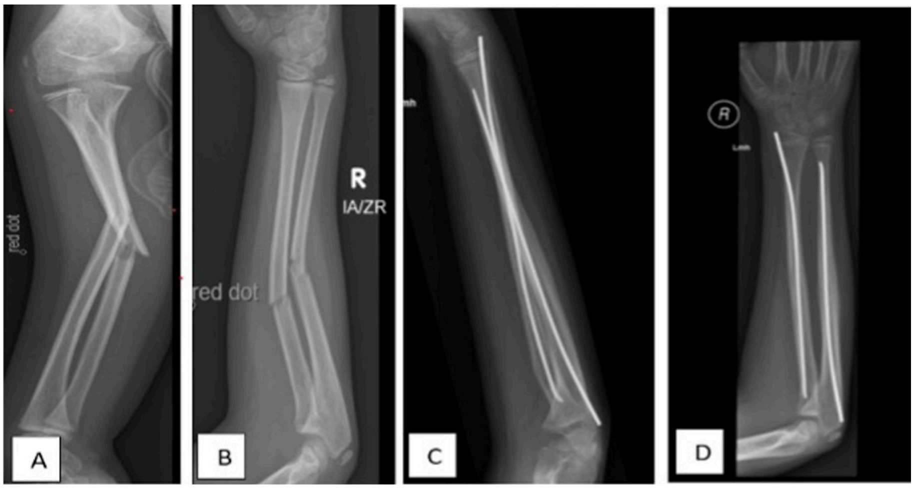

Figure 1 — Pre-operative (A) lateral and (B) anteroposterior (AP) radiographs showed a displaced fracture of the shaft radius and ulna. Union of fractures is at 10 weeks postoperatively on (C) lateral and (D) AP view with TENS nail.

Table I. — Patient demographics and fracture characteristic.s

	Number/%/ Mean/Range
Age	Mean 9.13 years (4-14 years)
Sex	
Boys	40 (61.5%)
Girls	25 (38.5%)
Side	
Right	31 (47.7%)
Left	34 (52.3%)
Weight(Kg)	Mean 32.62 Kg (17-66 kg)
Bone involvement	
Both Radius and Ulna	60 (92.3%)
Only Radius	3 (4.6%)
Only ulna	1 (1.5%)
Monteggia type fracture	1 (1.5%)
Level of fracture	
Proximal third	4 (6.2%)
Middle third	56 (86.2%)
Distal third	5 (7.7%)
Same level in both bone	47 (78%)
Different level in both bone	13 (22%)
Associated other fracture (Distal Radius)	1 (1.5%)
Open fracture (Gustillo Anderson Grade 1)	2 (3%)
Type of fracture- Comminuted	4 (6.2%)
Pre-operative nerve involvement	2 (3%)
(Sensory only)	
Ulnar nerve & Median nerve	1
Median nerve	1
Prior fracture same bone (Within 2yrs)	7 (10.8%)

only, 1 (1.5%) case of the ulna and 1 (1.5%) case of Monteggia type fracture. The fracture location was middle third in 56 (86.2%) patients, proximal third in 4 (6.2%) patients and distal third in 5 (7.7%) patients. Out of sixty children with both radius and ulna fractures, the fracture was on the same level in 47 (78%) and different levels in 13(22%). One child had an associated distal radius fracture treated with K-wire fixation. 7 (10.8%) children had prior fractures in the same forearm bones within the last two years. Two (3%) children had pre-operative nerve injury (one case of Ulnar & Median nerve sensory only, one case of median nerve sensory only). Both of them recovered fully by 7 weeks.

Out of 60 children with both forearm bone fractures, 50 (83.3%) were treated with TENS nailing of both bones. In some cases, the reduction of both bone fractures was adequate after the fixation of a single bone; this strategy was utilised in 10 patients. Isolated fixation of the radius was done in 7(11.7%) and that of the ulna in 3(5%) patients (Table II). There was one case of Monteggia-type fracture, treated successfully with closed reduction of the radial head and a TENS nail for the Ulna. 31 cases (47.7%) were treated with a 2mm nail. 15 (23%)with 1.5mm nails and 14 (21.5%) with 2.5 mm nails. A 3mm nail was used in one child. In the rest (4 cases), different nail diameter combination (1.5mm, 2mm and 2.5 mm was used to fix radius and ulna fractures (Table II).

77% of patients received surgical treatment within 48 hours of injury.

Overall, the minimal opening of the fracture site to openly reduce the fracture was needed in 25 cases (38.5%). In cases of both bone involvement, 15 (25%) patients required it both for the radius and ulna, 3 (4.6%) patients required it only for the ulna, 5 (8.4%) patients required it only for the radius. 2 out of 5 cases of single forearm bone fracture needed open reduction.

Table II. — Intraoperative variables, grade of the surgeon, union time and implant removal

	Mean/Numbers/%/Range
Surgical fixation (Both Bone fracture, n=60)	
Both Radius & Ulna	50 (83.3%)
Only Radius	7 (11.7%)
Only Ulna	3 (5%)
Surgical fixation (single forearm bone, n=5)	
Radius	3
Ulna	1
Monteggia	1
Injury surgery interval	
<48 hrs	50 (77%)
>48 hrs	15 (23%)
Tourniquets used	49 (75.4%)
Overall incidence of open	25 (38.5%)
Reduction both bone fracture	
Open reduction both bone	15 (25%)
Open reduction radius only	5 (8.3%)
Open reduction ulna only	3 (4.6%)
Reduction Single bone fracture	
Open reduction	2
Surgery performed by	
Consultant	19 (29%)
Registrar(supervised by consultant)	46 (71%)
Size of nail used	
1.5mm	15 (23%)
2mm	31 (47.7%)
2.5mm	14 (21.5%)
2mm,2.5mm	2 (3%)
2mm,1.5mm	2 (3%)
3mm	1 (1.5%)
Duration of surgery (minutes)	Mean 57.14 minutes (25-125 minutes)
Surgery performed by	
Consultant	19 (29%)
Registrar(supervised by consultant)	46 (71%)
Hospital stays	Mean 1.86 days (1-4 days)
Duration of plaster	Mean 6.7 weeks (3-12 weeks)
Radiological fracture Union time	Mean 10.34 weeks (6-20 weeks)
Follow-up	Mean 5.84 months (4-12 months)
Initial surgery and implant removal interval	Mean 20.12 weeks (9-32 weeks)

The surgery was performed by a Trainee in a Consultant supervised list in 46 (71%) and by a consultant in 19 (29%) cases. In 49 cases (76%) tourniquet was used during surgery. The average duration of surgery was 57.14 minutes (range: 25-125 minutes).

The average hospital stay for the children was 1.86 days (1-4 days). Post-operatively all children had plaster for an average of 6.7 weeks (3-12 weeks). The patients were followed-up for a mean duration of 5.8 months (range: 4-12 months). The average time to fracture union, defined as the presence of a bridging callus across three of four cortices on anteroposterior (AP) and lateral views of radiographs, was 10.4 weeks (range: 6-20 weeks).

The present study observed an overall complication rate of 41.5% (Table III). 14 out of 25 cases of open reduction are associated with some complication. We noticed a higher (56% vs 32.5%, $p=0.059$) rate of overall complication in open reduction compared to closed reduction cases (Table IV). Details of different complications are shown in Table III. In our series, one child (1.5%) had non-union and was treated with removal of the nail followed by plate fixation. In 4 children (6.2%), bony consolidation did not take place

Table III. — Complications

Complications	Number (%)
Overall complications	27 (41.5%)
Infection A) Superficial infection treated with antibiotics only B) Deep infection needed surgical debridement-/+early removal of implant	4 (6%) 2 2
Non-union	1 (1.5%)
Delayed union	4 (6%)
Nerve injury A) Superficial radial nerve palsy B) Median & radial sensory C) Medial & ulnar sensory	3 (4.6%) 1 1 1
Re fracture with nail insitu	1 (1.5%)
Re fracture post nail removal	2 (3%)
Restriction of forearm rotation (15-30 degrees) Restriction of forearm rotation (30-40 degrees)	5 (7.7%) 1 (1.5%)
Skin irritation due prominent ulnar hardware associated with olecranon bursitis	1 (1.5%)
2nd operative procedure due to complications	5 (7.7%)

Table IV. — Comparison of complications following TENS nailing between open and closed reduction of the fracture

	Open Reduction (n=25)	Closed Reduction (n=40)	P value
Complications	14(56%)	13 (32.5%)	*P=0.0595*

by 12 weeks and was classified as a delayed union. Four out of five cases of delayed union and non-union had an initial open reduction.

We had three (4.6%) cases of postoperative nerve injury (one case of superficial branch radial nerve, one case of combined median & radial nerve sensory involvement and one case of combined median and ulnar sensory nerve involvement). Injury to the superficial branch of the radial nerve was noted after the removal of the nail. Both the patients with combined nerve injury had an open reduction. All these cases recovered fully by 12 weeks.

There were 2 cases (3%) of superficial infection treated successfully with oral antibiotics, and 2 cases (3%) of deep infection & wound related complications were treated with debridement and early removal of the metalwork. The nail was removed eight weeks after surgery in the first patient, after the bony union. The second patient was protected in a cast after metalwork removal as it did not show bony union at the time of surgery.

One (1.5%) patient suffered a refracture with a nail in situ and was treated with the removal of nails followed by fixation with a plate. In 2 children (3%), a second fracture occurred in the same forearm due to further trauma, 5 and 11 months after nail removal. In both cases, the complete radiographic union was noted prior to refractures.

One child (1.5%) had skin irritation due to prominent ulnar metalwork and was associated with olecranon bursitis. It resolved fully after the removal of the nail.

Our series had no incidence of osteomyelitis, mal-union or secondary loss of correction, compartment syndrome, implant failure or implant breakage, limb length discrepancy, synostosis and restricted elbow or wrist movement.

Table V. — Functional outcome as per Price Criteria

Outcome	Symptoms	Loss of Rotation	Number (%)
Excellent	No complaints with strenuous activity	<15 degrees	59 (90.8%)
Good	Mild complaints with strenuous activity	15-30 degrees	5 (7.7 %)
Fair	Mild complaints with daily activity	30-90 degrees	1 (1.5%)
Poor	All other results	>90 Degrees	0

The average time to remove the implant was 20.12 weeks (range: 9-32 weeks).

According to the Price et al. criteria (Table V), excellent results were obtained in 59 patients (90.8%), good results in 5 (7.7%) and fair results in one (1.5%). Among the patients with good outcomes, all had a restriction of forearm rotation of 20 to 30 degrees in the last follow-up, and patients with fair results had restriction of supination of 30-40 degrees.

DISCUSSION

Given their ease of use, short operative time, minimal surgical dissection, safe conservation of alignment, availability to use in both closed and open fractures, and ease of removal makes, the use of elastic intramedullary nails a popular choice for fixation of fractures of forearm bones in children[9,10]. The biomechanical characteristics of the titanium elastic nail provides bending, axial, translational, and rotational stability to achieve optimal results[11]. Elastic titanium nails have become the standard of intramedullary fixation because of their biocompatibility, modulus of elasticity, osseointegration rate, corrosion resistance and MRI compatibility.

In our series, 38.5% of the fractures treated with TENs nailing required open reduction of at least one forearm bone, similar to the rate of open reduction in the literature, varying from 8-51%[12,13]. In our institution, the "10-minute rule" has been suggested as a good rule of thumb in the decision-making for the open reduction of these fractures. i.e., if the surgeon is unable to navigate the nails across the fracture site by the closed method in 10 minutes, the open reduction must be considered[14]. It has also been proposed that the fracture site must be opened after three failed closed reduction attempts[15]. Multiple failed closed reductions and longer operative times are associated with compartment syndrome[13]. In our series, no one had any compartment syndrome. Closed reduction or open reduction before IM nailing yields similar functional results, with a similar complication profile in paediatric diaphyseal fractures[16].

In our study,16.7% of both bone forearm fractures were treated with single bone fixation of the radius or ulna. In the literature, Single-bone fixation of the ulna has been reported to be safe and effective for unstable diaphyseal both-bone forearm fractures[17,18], whereas other authors suggested loss of reduction of the unfixed radius[19]. We found no differences in functional results and complications between these two groups.

In our study, the average duration of postoperative immobilisation was 6.7 weeks. Duration of postoperative immobilisation is variable in the literature ranging from no immobilisation and immediate movement to immobilisation in a long arm cast for six weeks.

The mean radiographic union time in our series was 10.3 weeks (range:6-20 weeks) which was similar to the mean union time in the literature of 8-13 weeks 8-13 weeks[20,21].

The average time for removal of the implants in this study was 20 weeks (range: 9-32 weeks). The minimum recommended time, in the literature, for implant removal is 16 weeks[22]. This recommendation is based on typical fracture healing time to minimise complications associated with early hardware removal, primarily refracture. At our institution, we prefer to remove implants between 16-24 weeks. This allows ample time for fracture healing and remodelling while avoiding difficulty in removing nails due to bony overgrowth. In our series, implants were removed earlier than 16 weeks in 10 patients (15.4%), of which four were for infection and wound complications. We noted no refracture in the group where the nail was removed before 16 weeks.

According to Price et al., Excellent to good results were obtained in over 98% of cases in our series. This is in accordance with previously reported results in the literature[6,16,20].

A wide range of complication rates between 4% to 67% for intramedullary nail fixation for both forearm bone fractures are reported in the literature[6,16,23]. In the present study, we observed an overall complication rate of 41.5%, of which 7.7% needed a second operative procedure. Also, 4 out of 5 cases requiring a second 2nd operative procedure were from the open reduction group. A higher (56% vs 32.5%, *p=0.059*) complication rate was noted in open reduction compared to closed reduction cases and was statistically significant. Open reduction of the fracture involves periosteal stripping and blood circulation disruption around the fracture, leading to higher complications due to a higher possibility of delayed union or nonunion[6,23]. Yalçinkaya M et al.[16]. reported similar functional results, with a similar complication profile in paediatric diaphyseal fractures treated with closed reduction or open reduction.

We noticed overall infection and wound related complications in 6% of cases, of which 3% had deep infections needing debridement and removal of metalwork. No case of osteomyelitis was found in our series. Most authors reported osteomyelitis as a very rare complication[20,23].

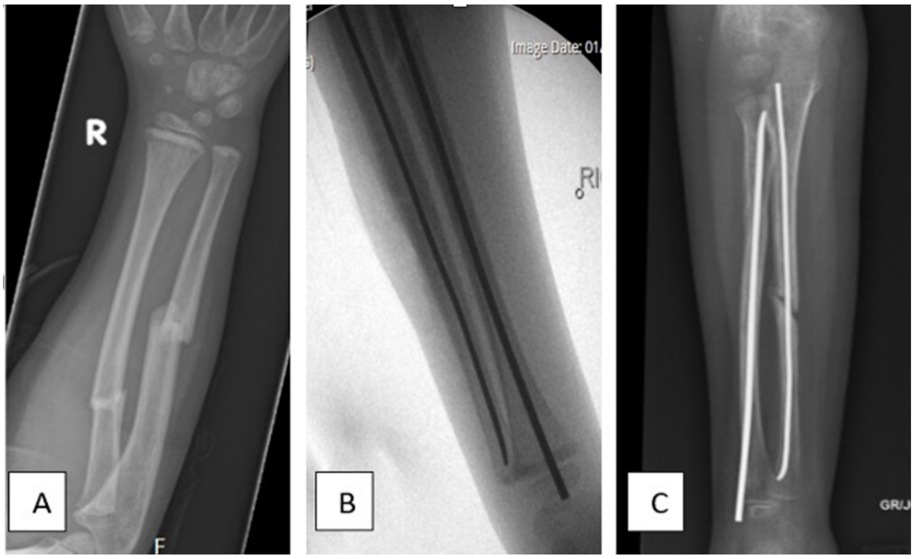

Figure 2 — Preoperative (A) radiograph showing displaced fracture of shaft radius and ulna. Intraoperative (B) radiograph showing fixation of radius and ulna with TENS nail. Postoperative (C) radiograph at 12 weeks showed complete union of the radius but delayed union of the ulna.

We noted 6% cases of delayed union and 1.5% cases of nonunion in our series.80% of our cases of delayed union and nonunion were associated with initial open reduction and limited to the ulna (Figure 2). Fernandez et al.[23]. reported 2.53% cases of delayed union and 7.26% cases of non-union, and all cases of non-union were limited to the ulna. A multicentre series by Schmittenbecher et al.[24] noted 1.87% of delayed unions and no non-unions out of 532 patients. Lieber et al.[25] documented 0.5% of delayed unions and no non-unions in a multi-centre study with 400 patients. The ulna is described to have a relative "watershed zone" regarding its blood supply in the middle third portion, which may predispose it to increased rates of nonunion and delayed union, relative to the radius. Also, open reduction of the ulna may remove the fracture hematoma and cause periosteal stripping, which may also predispose to delayed healing or non-union[23].

The injury to the superficial radial nerve can occur either during primary fracture treatment or metalwork removal. In our series, the overall incidence of nerve injury was 4.6%, of which 1.5% (1 case) was related to the superficial radial nerve. Fernandez et al.[23] reported a 2.7% incidence of superficial radial nerve injury. Good exposure and careful blunt subcutaneous dissection during the metalwork insertion and removal reduce the risk of nerve injury.

Re fracture is another complication after intramedullary nailing of forearm fracture in children. The risk of a forearm shaft refracture is reportedly approximately 3-8%[23,24]. In our series, the incidence of refracture was 4.6%, of which (one case)1.5% was refracture with the implant in situ. We did not find a higher incidence of refracture in open reduction cases or cases where the nail was removed earlier than 16 weeks. In their large series, Fernandez et al. reported a 2.5% rate of in-situ refractures[23]. Early hardware removal[7,23], open fractures or open reduction are associated with a higher rate of refracture[6].

Our study had several limitations. Our sample size is small (n=65). Since all data was collected from only one hospital, there is a chance of hospital practice bias. One limitation of the present study is its non-comparative nature. The retrospective nature of the study limits our data collection, forcing reliance on electronic records and operative reports.

Furthermore, the study population consisted of different types of forearm fractures, which are not directly comparable to each other. Despite careful interpretation of these resources, it is possible that the documentation and actual clinical events differed slightly. The follow-up length was limited and varied depending on the time of implant removal. However, all patients were followed up until fracture union.

CONCLUSIONS

In our experience, titanium elastic nailing is a safe, reliable, cosmetically acceptable and efficient method of internal fixation for irreducible or unstable fractures of both bones of the forearm in children and adolescents. More than one-third of our patients needed open reduction of the fracture. We noticed higher complications associated with open reduction of the fracture. Surgeons must be aware of the possible complications related to the nailing of forearm bone fractures and make every effort to mitigate them. However, some of the complications are unavoidable. Despite all complications, we noted excellent to good functional outcomes in most cases. A bigger sample, multicentre investigation with long-term follow-up may be needed to draw a definite conclusion.

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