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Elastic stable intramedullary nailing in pediatric diaphyseal forearm bone fracture

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ABSTRACT

Background: Pediatric forearm bone fracture present significant challenges where most of them are managed with closed reduction and casting. Irreducible, unstable and open fracture usually requires operative stabilization. Intramedullary nailing is considered minimal invasive however it is not free of complication. The aim of this study is to analyze the outcome and complications after elastic stable intramedullary nailing in pediatric diaphyseal forearm fracture.
Methods: A descriptive observational study was carried out for four years (2013-2016) in diaphyseal pediatric forearm fracture stabilized with titanium elastic stable intramedullary nailing. Final range of motion, complications and outcome were assessed using Clavien-Dindo classification modification appropriate for orthopedic surgery.
Results: We report the outcome of 36 patients with complete medical records. Closed reduction and nailing was successful in 25 patients (69.4%) whereas eleven patients (30.6%) required open reduction (both radius and ulna in 6 patients 16.7%, ulna in 3 patients 8.3% and radius in 2 patients 5.6%). Radiological union was achieved at an average of 7.75±1.5 weeks (range 6 to 16 weeks). Forearm rotation was limited in 7 patients with average loss of 16° pronation and 18° supination. The overall rate of complication was 22.2%. According to Clavien-Dindo classification excellent results were noted in 29 patients (80.6%), good in 3 patients (8.3%) and fair in 4 patients (11.1%).
Conclusions: Elastic intramedullary nailing in pediatric diaphyseal forearm bones fracture is minimally invasive with low rate of complication and the outcomes are fair to excellent.

Keywords: Elastic intramedullary nailing, Forearm, Fracture, Complication

INTRODUCTION

Pediatric fractures present significant challenges to the orthopaedic community. Diaphyseal forearm bone fractures are the third most common fracture in the pediatric population and account for 13-40% of all pediatric fractures.[1]

90% of pediatric forearm bone fractures are successfully treated conservatively by closed reduction and casting.[2] Re displacement is the most common complication in cast immobilization after diaphyseal forearm fracture and is reported to occur in 5-15 % of the cases leading to angular or rotational malunion resulting in functional disability.[3] Considering the unpredictable remodelling capacity in older children and the importance of minimizing angular deformity to preserve the normal forearm rotation, operative management of pediatric forearm bone fractures has become popular. Common operative indications are open fractures, irreducible fractures, unstable fractures, floating elbow injuries, pathological fractures, significantly maluniting fractures. Well established surgical options include intramedullary nailing, osteosynthesis with plate and screw fixation, and external fixators.[4] Intramedullary nailing has shown encouraging clinical results and has been rapidly adopted as a minimally invasive treatment compared with plate fixation. Elastic stable intramedullary nailing (ESIN) are increasingly being used because of their elastic properties which allow for improved insertion and rotation while still providing adequate fracture stabilization.[5] However ESIN in pediatric forearm bone fracture treatment is not free of complication. Complications include prominent hardware, hardware migration, neurological deficits, delayed union, nonunion, radioulnar synostosis, compartment syndrome, tendon rupture, refracture and wound problems, including bursitis.[6] The aim of this study is to evaluate the outcome and complication of elastic intramedullary nailing for the treatment of pediatric diaphyseal forearm bone fracture.

METHODS

A descriptive observational study was conducted at Karnali Academy of Health sciences teaching hospital Nepal among the pediatric patients treated operatively for a diaphyseal forearm bone fracture from January 2013 to December 2016 after ethical approval from the Institutional Review Board. We report only those patients in whom both bones were stabilized solely using ESIN with a inclusion criteria of age 5-15 years, displaced and grossly rotated diaphyseal forearm bone fractures, failed closed manipulation, open fracture (Gustilo and Anderson Grade I and II), patients with adequate follow-up and complete medical records. Patients with isolated forearm bone fracture, open fracture (Gustilo and Anderson Grade IIII), floating elbow injuries, fracture with neurovascular injury, pathological fractures, Galeazzi or Monteggia fracture-dislocations, metaphyseal forearm bone fractures were excluded from the study. Initially, all the fractures were immobilized in long arm posterior slab in the emergency room. A subsequent attempt was made for closed reduction under appropriate anesthesia and fluoroscopic guidance. Upon failure of closed reduction, unacceptable length rotation and alignment or loss of reduction at regular follow up, a decision for surgery was made. We followed the acceptable reduction parameter for pediatric forearm fracture as per the recommendation made by Noonan and Price et al as given in Table 1.[7]

Table 1: Acceptable reduction parameters for forearm fractures in pediatric patients.

Parameter	Patient sex and age	
	Girls ≤8 year and boys ≤10 year	Girls >8 year and boys >10 year
Mid shaft Angulation (degrees)	15	10
Rotational deformity (degrees)	≤45	≤30
Translation (%)	≤100	<100
Shortening (mm)	≤10	-

Open fractures were managed with wound debridement, antibiotics, and unsuccessful attempts of closed reduction under fluoroscopic guidance resulted in a decision for surgery. Patient's age, sex, side, mechanism of injury, fracture type (closed/open), operative indication, reduction method (closed/mini open), time of clinical and radiological union, complication and final range of motion (ROM) were evaluated at subsequent follow up after taking an informed written consent. No extra financial burden was given to the patients.

Table 2: Modification of the Clavien-Dindo classification of surgical complications.

Complication grade	Definition	Examples
1	Deviation from a routine postoperative course without the need for intervention	Asymptomatic delayed union Prominent implant
2	Resolution after outpatient management, pharmacologic therapy, or close observation	Superficial infection Transient nerve palsy
3	Requiring inpatient management or reoperation	Deep infection Implant migration requiring early Removal
4	Complication that is limb threatening, life threatening, or resulting in a permanent deficit	Compartment syndrome Permanent nerve palsy Radioulnar synostosis Tendon rupture
5	Death of patient	Postoperative mortality secondary to anesthetic reaction

Table 3: Outcome grading system.

Outcome grade	Range of motion	Complication grade
Excellent	Full	Grade 1 or none
Good	Loss of <10 degrees pronation and/or supination	Grade 2 or less
Fair	Loss of 10 -30 degrees pronation and/or supination	Grade 3 or less
Poor	Loss of >30 degrees pronation and/or supination	Up to grade 5

Fracture union was defined as the radiological appearance of bridging callus at the fracture site on both the planes together with a pain-free fracture site. Delayed union was defined as incomplete consolidation at 90 days whereas incomplete healing by 6 months was considered as nonunion.[8] Complications and outcome were assessed using Clavien-Dindo classification with modifications appropriate for orthopedic surgery as presented in Table 2.[9] This outcome grading system considers final ROM and the occurrence of complications related to the treatment as shown in Table 3. Normal forearm ROM was considered to be 70 degrees of pronation and 85 degrees of supination.[10,11] Data analysis was done using statistical package for social sciences (SPSS Inc. version 17, Chicago, Illinois).

Surgical technique

A pneumatic tourniquet was used in all patients. Under appropriate anesthesia using image intensifier radial nailing was done retrogradely. Diameter of elastic nail used varied from 2-2.5 mm depending upon the diameter of medullary cavity at the level of isthumus. The nail length was measured from distal to the proximal growth plate under image intensifier. The radial nail is bent to about 20 degrees to match the radial bow and to ensure restoration of the interosseous space. Nail was advanced through a radial entry point made by an awl, 2-3 cm proximal to the distal radial epiphyses. The nail is attached to T handle and with rotatory movements advanced proximally up to fracture site. Attempts of closed reductions were made under fluoroscopic guidance to advance the nail into proximal radial fragment .The pre bent tip allowed easy passage of the nail through the medullary canal and also aids in fracture reduction. Optimal care was taken not to injure extensor tendons and superficial radial nerve.

Ulnar pin was inserted antegradely through the lateral border of olecranon just distal to the physis in the metaphysis. The ulnar pin only requires minimal pre bending of about 10 degrees because the bone is almost straight. This pre bending helps in three point fixation of the nail inside the ulnar bone canal and thus theoretically provides better fracture stability. All the nails were buried 4-5mm above the cortical bone and the skin was closed in layers after thorough lavage. Reductions were attempted closed in all the cases however with failed attempts mini open reduction was done at the fracture site with minimum stripping of the periosteum.

Post operatively, a long arm posterior splint was applied in all cases for six weeks. Active finger movements were encouraged after operation. Active and active assisted intermittent flexion and extension of wrist and elbow was started from second postoperative day. Supination and pronation of forearm was allowed after removal of splint at six weeks.

RESULTS

Out of 42 patients enrolled in this study six were lost to follow up so we report 36 patients who underwent ESIN for diaphyseal forearm fracture. The demographic data including patient, fracture and treatment characteristics are tabulated in Table 4. In 23 patients (63.9%) with unstable fractures, irreducible fractures including open fractures ESIN was performed as a primary procedure at an average of 3.6 days (range 0 to 8 days). Thirteen patients (36.1%) had ESIN performed as a secondary procedure either due to unacceptable reduction or re displacement in cast immobilization at an average of 9.5 days (range 7-14 days). Closed reduction and ESIN was successful in 25 patients (69.4%) whereas 11 patients (30.6%) required mini open reduction.

Table 4: Patient, fracture and treatment characteristics.

Variables	Values
Age	10.06±2.2 years (range 5-13 years)
Sex	
Male	30 (83.3%)
Female	6 (16.7)
Side of fracture	
Right	20 (55.6%)
Left	16 (44.4%)
Mechanism of injury	
Simple fall on to outstretched hand	16 (44.4%)
Fall from height	11 (30.6%)
Sports related injuries	5 (13.9%)
Bicycle accident	3 (8.3%)
Physical assault	1 (2.8%)
Type of fracture	
Closed	32 (88.9%)
Open	4 (11.1%)
Reduction methods	
Closed reduction	25 (69.4%)
Open reduction both radius and ulna	6 (16.7%)
Open reduction ulna	3 (8.3%)
Open reduction radius	2 (5.6%)
Average postoperative hospital stay	3.89±1.2 days (range 3-7 days)
Average time to radiological union	7.75±1.5 weeks (range 6-16 weeks)
Average time of follow up	12±2.4 months (range 8-18 months)

Complication was seen in 8 patients (22.2%). Delayed union of ulna was seen in one patient with grade II open fracture of ulna. Union was achieved in this case at 16 weeks without any further intervention. Six patients were noted to have Grade II complication. Three patients had prominent implant with skin irritation over entry site which resolved after elective implant removal. Temporary hypoesthesia in the area of superficial radial nerve was found in two patients. There was retrograde migration of ulnar pin with skin penetration requiring acute removal after 4 month of surgery in one patient. One patient developed olecranon bursitis as Grade III complication due to ulnar nail irritation which resolved after nail removal and bursectomy as given in Table 5.

Table 5: Complications, final ROM and outcomes.

Variables	Characteristics	No. of cases
Grades of complication		
Grade 1	Asymptomatic delayed union	1
Grade 2	Prominent implant with skin irritation	3
	Postoperative Superficial radial nerve neuropraxia	2
	Implant migration requiring removal	1
Grade 3	Olecranon bursitis	1
Grade 4		0
Grade 5		0
Overall complication		8
ROM		
1	Full	29
2	Loss of <10 degrees pronation and/or supination	3
3	Loss of 10-30 degrees pronation and/or supination	4
4	Loss of >30 degrees pronation and/or supination	0
Outcomes		
Excellent		29
Good		3
Fair		4
Poor		0

Forearm rotation was equal to the unaffected side in 29 patients (80.6%) whereas 7 patients (19.4%) had some loss of rotational movements, the average loss being 16° pronation and 18° supination. There were 3 patients (8.3%) with <10° loss and 4 patients (11.1%) with 10 to 30° loss of rotational arc. As per Clavien-Dindo classification outcome were excellent in 29 patients (80.6%), good in 3 patient (8.3%), fair in 4 patient (11.1%) and no poor outcome was noted. Nail removal was performed on an average of 8.14±2.2 months (range 4 - 14 months) following primary fixation as a day case procedure and was free of complication in all except one patient who developed a superficial wound infection which healed with appropriate treatment. The mean follow-up period was 12±2.4 months (range 8 to 18 months).

Figure 1: (a) Radiograph of 6 years old male with left diaphyseal forearm bone fracture.

Figure 1: (b) Healed postoperative radiograph with ESIN in situ.

Figure 1: (c) Radiograph after implant removal at 6 months.

DISCUSSION

Historically, the majority of pediatric diaphyseal forearm bone fractures have been treated with non-operative management relying on closed reduction and casting. However, diaphyseal forearm fractures treated conservatively are known to remodel poorly compared to the distal one-third, with a higher incidence of malunion.[12] The unpredictable remodelling capacity especially in older children can lead to loss of forearm rotation resulting in poor functional outcomes; therefore, operative treatment may be needed for the unstable, irreducible or open diaphyseal forearm fractures. Cadaveric studies have put some insight into rotational loss after malunion of forearm bone fracture. Matthews et al in their cadaver study concluded that little significant loss of forearm rotation resulted from angulations of 10° in any direction whereas with ≥20°of angulation, there was statistically significant and functionally important loss of forearm rotation.[13] Another cadaver study by Tarr et al showed that supination losses were much more obvious than pronation losses in middle third forearm fractures and rotational deformities produce loss of pronation–supination that were proportional to the degree of deformity.[14]

According to Shoemaker et al the ideal mode of fixation of pediatric forearm fractures should maintain alignment, be minimally invasive and inexpensive, and carry an acceptable risk profile.[15] Compared with open reduction and osteosynthesis with plate-screw fixation, intra-medullary nailing meets these criteria.

The main advantages of intramedullary nailing include maintenance of reduction, provision of an inexpensive, less invasive, relatively easy application, protection of bone alignment by three point contact, acceleration of bridging callus formation through micro movements at the fracture site, and thus contribution to rapid bony healing.[16] Intramedullary fixation materials include Steinmann pins, K-wires, Rush pins, and elastic titanium nails. In the clinical setting, titanium is being used more often than stainless steel because of the elastic properties which allow for improved insertion and rotation. However as with any surgical procedure complications can arise after ESIN treatment.

Closed reduction was successful in 25 patients whereas open reduction was inevitable in 11 patients (30.6%). The rate of open reduction with intramedullary nailing of pediatric forearm fracture in published literature ranges from 7.4% to 75%.[17-20, 22, 26] Luhmann et al advocated that open reduction with a small incision would cause much less trauma to tissues than that caused by multiple reduction maneuvers.[21] In this study 11 patients underwent mini open reduction when acceptable reduction could not be achieved or to overcome the interposed soft tissue and their outcome was similar to patients treated with closed reduction and intramedullary nailing though we did not compare the outcome between them. Yalcinkaya et al concluded that closed reduction or open reduction with a mini incision yield similar functional results and a similar complication profile in the treatment of pediatric unstable diaphyseal forearm fractures.[2]

Eight (22.2%) out of 36 patients suffered from some form of complications in this study. Cullen at al reported complications as high as 50% following intramedullary fixation of pediatric forearm fractures.[22] Martus et al reported a complication rate of 21% in their largest report of pediatric forearm fractures treated with intramedullary nailing.[23] The cause of these complications is difficult to determine, is it due to the surgeon's inexperience with the technique or the surgery itself, some consider the second procedure to remove the implants to be a disadvantage of intramedullary nailing.[24]

One patient with grade II open fracture had delayed union of ulna which could be due to extensive soft tissue damage from high energy trauma. There was no radiological sign of fracture being fixed in distraction however it healed without any further intervention. Antabak et al reported one case of delayed union among 88 patients treated for pediatric forearm fracture.[25] Delayed union is more common in ulna after intra-medullary nailing. Ogonda et al described that antegrade nailing of ulna may cause fracture site distraction and thus delay in bone healing.[27] Additionally, injury in the middle third of shaft of ulna is considered critical as regards to the intraosseous circulation and it may compromise bone healing.[28]

Prominent implant with skin irritation was noted in three patients. In this study all the nails were buried under the skin leaving the tip 4-5 mm out of cortex for later ease of removal. In our opinion too proud tip of elastic nail can cause overlying bursitis leading to skin irritation. Kelly et al found no significant difference between buried and exposed intramedullary implants after fixation of pediatric forearm fractures.[29]

Temporary hypoesthesia in the area of superficial radial nerve was found in two patients. Lyman et al encountered three cases of superficial radial nerve palsy among 86 titanium elastic nailed patients.[6] We consider this nerve injury as a traction based neuropraxia which resolves with time. This nerve injury can occur during primary nailing or at the time of implant removal. Adequate exposure of radial entry site with meticulous soft tissue dissection is utmost to prevent neuropraxia however identification of superficial radial nerve is not mandatory. We did not get compartment syndrome, radioulnar synostosis, nonunion as complication in this series. Similarly no case of EPL rupture was encountered and no case of refracture after implant removal is noted till date.

Limitation in the supination and pronation is the most common functional deficit after malunited forearm fracture. Price et al have suggested that when malunion is greater than 10° in the middle third forearm rotation can be limited by 20-30°.[30] Out of 36 patients in our study 29 patients (80.6%) had normal forearm rotation and normal flexion and extension of elbow and wrist. Forearm rotation was found to be limited in seven patients (19.4 %) but none of these patients complained of pain or any limitation in performing daily activities. We reviewed the radiographs in subsequent follow up and found no evidence of malunion to account for this limitation of movement. We consider that this limitation may be due to interosseous membrane fibrosis or poor compliance in post-operative ROM exercise.

Outcome was graded using Clavien-Dindo classification modification appropriate for orthopedic surgery. The advantage of this classification is the elimination of the potential subjective bias that is associated with the grouping of complications in grades as minor/major or mild/moderate/severe and it provides objective method for complication stratification. Using this classification we observed excellent results in 29 patients (80.6%), good in 3 patients (8.3%) fair in 4 patients (11.1%) and no poor outcome was noted. Martus et al used this new outcome grading system in their study and found excellent results in 163 patients (79.5%), good in 24 (11.7%), fair in 5 (2.4%), and poor in 8 patients (6.3%).[30]

Observational study on a homogenous group of patients whose diaphyseal forearm bones were fixed solely using titanium elastic nails could be the strength of this study. Sample size, study duration and non-comparative nature are its limitations. However this study will serve as a baseline data in future in demonstrating the differences between intramedullary nailing vs. plate fixation and closed vs mini open intramedullary nailing for pediatric diaphyseal forearm bone fractures.

CONCLUSION

ESIN meets the modern standards of biological osteosynthesis and offers ease of application, improved cosmesis, shorter operating time even when mini open reduction is required and easy removal. ESIN in pediatric diaphyseal forearm bone fracture seems to be an effective treatment option with good to excellent outcome and low rate of complication most of which resolve after hardware removal.

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