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Functional outcome of elastic stable intramedullary nailing of diaphyseal fractures of paediatric long bones

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ABSTRACT

Background: After the advent of titanium elastic nails (TENs) and gratifying results of elastic stable intramedullary nailing (ESIN) in diaphyseal fractures of paediatric long bones, not only the parents of patients are opting surgical treatment over conservative, but also more and more orthopaedicians are offering ESIN with TENs to obviate the inherent problems of conservative treatment. We took up this study to evaluate the functional outcome of ESIN with TENs.
Methods: 44 patients aged 5-15 years suffering from diaphyseal fractures of femur, tibia, humerus, and forearm bones were treated by ESIN with TENs.
Results: All 44 patients showed uneventful union, femur in an average period of 8.3 weeks, tibia in 7.3 weeks, forearm bones within 7 weeks and humerus in 7.5 weeks. Commonest complication was pain at insertion site. 1 femur patient had lengthening of 1.5 cm. 1 femur and 1 forearm patient showed joint stiffness. No patient had delayed/non-union, sagittal/coronal/rotational mal-union, and deep infection. Partial weight bearing (PWB) started from 2nd/3rd day attaining full weight bearing (FWB) in 6-10 weeks.
Conclusions: ESIN with TENs appears logical and safe to obviate the inherent problems of conservative treatment, as ESIN is least invasive and allows early PWB/FWB leading to early independence of personal hygiene/toilet use with early social integration/return to school.

Keywords: Diaphyseal fractures, Paediatric long bones, Intra-medullary fixation

INTRODUCTION

The diaphyseal fractures of paediatric long bones are very commonly encountered in orthopaedic practice. Conservative treatment is considered ideal for these fractures and is carried by spica with or without initial traction for femur, manipulation, reduction and cast immobilization for tibia, humerus and forearm bone fractures.

Prolonged bed rest/immobilization is linked to mental/psychological problems in adolescent patients.[1] Moreover, conservative treatment carries a risk of residual angulation/mal-rotation, and limb length discrepancy (LLD).[2,3] Though several operative treatments e.g. plate osteosynthesis, external fixators, and intramedullary nailing, are available, but plate osteosynthesis requires large exposures with risk of fracture at the end of plate or through the screw holes after plate removal and has also been linked to a higher incidence of over growth vis-a-vis intramedullary fixation in cases of femur.[4-6] External fixation, though a simpler technique, is associated with pin tract infection, delayed/nonunion.[7,8] Solid antegrade intramedullary nailing is a good option for femur fractures in adults, but in skeletally immature patients it is linked with avascular necrosis of head of femur, trochanteric epiphysiodesis, and coxa valga.[9-12]

Over the past few years there has been a marked increase in intramedullary fixation for diaphyseal fractures in children. Intramedullary fixation is not new, in mid 19th century ivory pins were used which were later supplanted by other metal implants e.g. Kuntscher's nail which offered great stability, but in growing children there was a risk of physeal damage. Then slightly flexible Rush nail was introduced which was forerunner of modern elastic intramedullary fixation. Hackethal and Marchetti used bundle of thinner wires filling the medullary canal, and then Ender developed his nail improving quality of fixation.[13]

In early 1980s, surgeons in Nancy, France, developed elastic stable intramedullary nailing [ESIN] based on the concept of Firica.[13,14] These surgeons improved stability significantly by using two pre-tensioned nails inserted from opposite side of the bone imparting excellent axial and lateral stability to diaphyseal fractures of paediatric long bones. Rotational stability was also comparatively better. These nails could be used in an antegrade or retrograde fashion without crossing the physis.

The treatment of paediatric long bones fracture has of late been dramatically changed after the development of flexible stable intramedullary titanium elastic nails (TENs). ESIN represents a compromise between conservative and surgical treatment.[15] The method originally invented for femur gradually became applied for other long bones also.[16]

The purpose of this study was to evaluate the functional outcome of ESIN in diaphyseal fractures of paediatric long bones.

METHODS

This study has been conducted, for 44 patients aged 5-15 years, in the department of orthopaedics at Subharti Medical College, Swami Vivekanand University Meerut, for a period of 2 years from 2013-2015. All patients with displaced diaphyseal fractures, closed/compound, Gustilo-Anderson grade-I and II, attending OPD/casualty department were included in the study. Patients below 5 years were not included due to small volume of the medullary canal which may not allow easy passage of TENs, moreover these children can very well be treated conservatively, while the patients above 15 years are near to the closure of physis after which rigid intramedullary nailing can be done in femur without the risk of avascular necrosis of head of the femur.[13,16]

Parents of every patient were counselled about the benefits of ESIN vis-à-vis conservative treatment, and a written consent from parents was obtained for inclusion into the study.

Out of 44 patients, 22 (50%) belonged to 5-10 years group and rest 50% to 10-15 years group, youngest being 5 years and eldest being 15 years old, with mean age of 8.2 years. There were 31 (70.5%) males and 13 (29.5%) females with a male to female ratio of 2.38:1.

Femur was commonest fractured bone affecting 27 (61.40%) patients, followed by tibia 9 (20.45%), forearm bones 6 (13.60%), and humerus 2 (4.55%). 25 (56.8%) patients sustained injury to right sided extremities, while 19 (43.20%) patients to left sided limbs.

Majority of fractures were in middle 1/3rd. 17 (63.0%) femur fractures were in middle1/3rd, 5 (18.5%) in upper and 5 (18.5%) in lower 1/3rd. 5 (55.6%) tibia fractures were in middle 1/3rd, and 4 (44.4%) in lower 1/3rd. 3 (50 %) forearm fractures were in middle 1/3rd, 2 (33.3%) in lower 1/3rd, and 1 (16.7%) in upper 1/3rd. 2 (100%) humerus fractures were in upper 1/3rd.

Majority of fractures were biomechanically transverse in nature. 17 (63%) femur fractures were transverse, 9 (33.3%) oblique, and 1 (3.7%) spiral. 6 (67%) tibia fractures were transverse, 2 (22%) oblique, and 1 (11%) comminutted. 5 (83.3%) forearm fractures were transverse, and 1 (16.7%) oblique. 1 (50%) humerus fractures was transverse, and 1 (50%) oblique.

42 (95.5%) fractures were close and only 2 (4.5%) were open, one in forearm (Gustilo-Anderson type-I), and one in tibia (Gustilo-Anderson type-II).

Technique

TENs are prebent so that apex of the curve lies against the endosteal surface of the fracture. Two equal sized prebent nails are inserted, which provide three point buttressing imparting maximum stability to the construct and the fracture as shown in Figure 1.

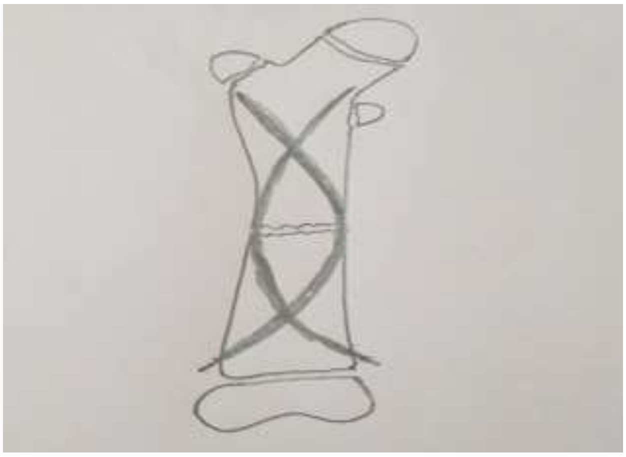

Figure 1: The sketch diagram showing three point buttressing principle of elastic stable intramedullary nailing [ESIN] imparting stability to the construct and fracture.

The diameter of each nail should be about 2/5th or 40% of the narrowest internal diameter of the medullary canal. The entry portals are made in the metaphysis by small incisions and cortices are perforated with awl. The nails are advanced into the medullary canal upto the fracture site. The fracture is reduced and nails are driven across the fracture impacting them into the opposite metaphysis without damaging the physis. Nails are cut 1.5 cm long from the entry portal for an easier subsequent removal.

For femur fractures

A fracture table helps in reduction. Two nails from lower metaphysis, one from medial and one from lateral side about 1.5-2 cm proximal to distal physis, are advanced across fracture and impacted into the proximal metaphysis, one towards the greater trochanter and the other into the neck of femur without violating the sub capital femoral epiphysis or trochanter apophysis.[3,5]

For tibial fractures

The entry portals are made in the proximal metaphysis, one on medial and one on lateral side, about 1.5-2cm distal to the proximal physis, and nails are embedded into the distal metaphysis without violating the cortex or the physis.[3]

For humerus fractures

For upper and middle1/3rd fractures two nails are passed from lateral cortex just above the distal physis through separate holes made one above the other. For lower 1/3rd fractures two nails are passed from lateral cortex at the level of deltoid insertion through separate holes made one above the other.[2]

For radius/ulna fractures

A single nail of 2-2.5 mm is passed in the radius from just proximal to the distal physis on the radial border, while in ulna from just distal to the proximal physis on its radial border, a point easily palpable proximal to the head of radius or alternatively through the tip of olecranon which though violates the physis but growth arrest is uncommon.[2]

RESULTS

In our study of 2 years, 44 patients of diaphyseal fractures were treated with TENs. All 27 (61.40%) femur fractures with a mean age of 9.5 (range 5-14) years were treated by retrograde nailing with two TENs, while all 9 (20.45%) tibia fractures with a mean age of 9.6 (range 6-13) years were treated by antegrade nailing with two TENs, however in 6 (13.60%) forearm fractures with a mean age of 12.2 (range 11-15) years, ulna was stabilized by antegrade nailing and radius with retrograde nailing with single TEN in each bone. 2 (4.55%) humerus fractures with a mean age of 11.5 (range 8-15) years were treated by retrograde nailing with two TENs as given in Table 1. Only 2 of 27 femur fractures were immobilized with thigh corset, one for 4 weeks due to long spiral fracture, and other for 6 weeks due to patient's overweight, to prevent angulation.

Table 1: Showing total number of patients in each group of bone involved with patient's mean age in years and type of nailing done.

Bone Involved	Total patients	Mean age (years)	Range of age (years)	Nailing type (Retro/Antegrade)
Femur	27	9.5	5-14	Retrograde
Tibia	9	9.6	6-13	Antegrade
Forearm bones	6	12.2	11-15	Radius – Retro; Ulna - Ante
Humerus	2	11.5	8-15	Retrograde

All 9 tibia fractures were immobilized with Delbet cast for 4 weeks. All 6 forearm fractures were given above elbow cast for 4 weeks to restrict forearm rotation because of single nail fixation. No immobilization was given for humerus fractures.

All patients of lower limb fractures were allowed partial weight bearing (PWB) ambulation with walker support from 2nd/3rd postoperative day, gradually progressing to full weight bearing (FWB) as the union advanced within 6-8 weeks. 20 femur and 7 tibia patients attained FWB walking within 6-8 weeks, while 6 femur and 2 tibia patients attained FWB within 8-10 weeks. However one femur patient showed rapid union attaining FWB within 4-6 weeks as in Table 2.

Table 2: Showing range of time period in weeks for full weight bearing after ESIN of diaphyseal fractures of femur and tibia.

Time Period	No. of Cases	Bone Involved
4-6 weeks	1	1 Femur
7-8 weeks	28	20 Femur, 8 Tibia
9-10 weeks	7	6 Femur, 1Tibia

All 44 patients showed uneventful union. All femurs united within an average of 8.3 (range 4-10) weeks, tibia in 7.3 (range 6-10) weeks, forearm bones within 7 (range 6-8) weeks and humerus in 7.5 (range 6-8) weeks as shown in Table 3.

Table 3: Showing average period of time to union after ESIN in each group of bones.

Bone involved	Average timing of bone union (weeks)	Range (weeks)
Femur	8.3	5-10
Tibia	7.3	6-10
Forearm bones	7	6-8
Humerus	7.5	7-8

The commonest complication was pain at insertion site with or without skin erosion. 5 patients (femur -3, tibia -1, forearm -1) complained of pain at insertion site, 2 of which suffered skin erosion. 1 femur patient had lengthening of 1.5 cm. 1 femur and 1 forearm patient showed restriction of knee flexion beyond 45^0, and 20^0 supination of forearm respectively. No patient had delayed/non-union, sagittal/coronal/rotational mal-union, and deep infection as given in Table 4.

Table 4: Showing type and incidence of complications after ESIN.

Type of Complication	No. of Patients
Joint stiffness	2 (F-1, F.A-1)
Pain at insertion site +/- Skin erosion	5 (F-3, T-1, F.A-1)
Limb length discrepancy	1 (F-1 only)

F- Femur, T- Tibia, FA- Forearm bones, H- Humerus

On an average, hardware from femur was removed at 7.8 (range 6-9) months, from tibia at 6.94 (range 6-9) months, from both bones of forearm at 4.8 (range 4-8) months, and from humerus at 3.5 (range 3-5) months as in Table 5.

Table 5: Showing average time of hardware removal in each group of bones.

Bone involved	Average timing of hardware removal (months)	Range (months)
Femur	7.8	6-9
Tibia	6.94	6-9
Forearm both bones	4.8	4-8
Humerus	3.5	3-5

Results of femur fractures by Flynn's criteria were excellent in 22 (81.5%) patients, and successful in 5 (18.5%) patients.

Results of forearm fractures by Price et al criteria were excellent in 5 (83.3%) patients, and good in 1 (16.7%) patient. The results of tibia and humerus fractures by clinico-radiological assessment were satisfactory in all 9 (100%) tibia and 2 (100%) humerus fractures as shown in Table 6.

Table 6: Showing functional outcome of ESIN in each group of bones.

Bone involved	Number of cases	Criteria of functional assessment	Results	No. of cases with percentage
Femur	27	Flynn's Criteria	Excellent	22 (81.5)
			Successful	5 (18.5)
			Poor	Nil (0)
Tibia	9	Clinico-radiological	Satisfactory	9 (100)
			Unsatisfactory	Nil (0)
Forearm bone	6	Price et al Criteria	Excellent	5 (83.3)
			Good	1 (16.7)
			Fair	Nil (0)
			Poor	Nil (0)
Humerus	2	Clinico- Radiological	Satisfactory	2 (100)
			Unsatisfactory	Nil (0)

DISCUSSION

There is no denying that conservative treatment of diaphyseal fractures of paediatric long bones is considered ideal and has stood the test of time.[17] But with the changing scenario of family set ups from joint to nuclear ones with both parents working and due to inherent problems of conservative treatment (re-displacement, angulatory/rotational malunion, LLD, long hospital stay in cases of traction treatment keeping one of the parent off duty, personal hygiene problems, psychological problems as the child is kept away from peer group and school due to immobility in cases of lower limb fractures) more and more parents are now opting for surgical treatment due to obvious advantages like short hospital stay, less off duty for parents, low risk of re-displacement and malunion, and rapid social reintegration of the child as a result of early mobilization.[1-3] Due to aforesaid advantages coupled with very favourable and promising results, more and more orthopaedic surgeons are also now offering surgical treatment for diaphyseal fractures of paediatric long bones in an effort to evade the unpleasant physical, psychological, and social side effects of conservative treatment.[17]

Though external fixators, compression plates, rigid intramedullary nails, all have been used with good results but with certain definite disadvantages such as large exposure and risk of fracture at the end of plate or through screw holes after removal of plate, pin tract infection and higher risk of re-fracture with external fixators along with a risk of restriction of knee movements as excursion of iliotibial band is restrained due to penetration of pins of fixator through it, avascular necrosis of femoral capital epiphysis/trochantric epiphysiodesis and coxa valga after rigid intramedullary nailing when done through the pyriformis fossa probably due to injury to the posterosuperior branches of medial femoral circumflex artery.[4-12,18]

With the advent of ESIN in early 1980s in Nancy, France [13] the disadvantages of other surgical devices could be obviated and the diaphyseal fractures were started being stabilized with two pre-tensioned nails without violating the physis and fracture hematoma which yielded promising results with minimal complications. Moreover, ESIN provides sufficient stability to allow immediate ambulation on the operated extremity gradually progressing from initial PWB to FWB as the union advances, as intramedullary pins act as load sharing devices.[16,18] ESIN permits micro-motion at the fracture site while resisting angular and rotational forces resulting into an indirect healing by the generation of external callus.[19] At the outset only femur fractures were treated with ESIN, but because of gratifying results, its use was extended to other bones also.[16] ESIN with TENs is considered as a middle path between conservative and operative treatments.[15]

The technique of ESIN is simple, minimally invasive requiring only small incisions without violating physis/fracture hematoma, allows early ambulation while maintaining reduction, and its elasticity allows micro motion at the fracture site resulting into rapid callus formation bridging the fracture gap. ESIN though appears an attractive option it does have a minimum and maximum age bar. The minimum age recommendation is 5 years due to inadequate volume of medullary canal of paediatric bones, which may not allow easy passage of nails, thereby leaving the younger patients more suitable for conservative treatment, while the upper age limit is till the physis is not closed after which other fixation modalities may become more suitable.[16]

In this study, 44 patients aged 5-15 years were treated by ESIN with TENs. There were 31 (70.5%) males and 13 (29.5%) female patients with a male to female ratio of 2.38:1. 25 (56.80%) patients sustained injury to right extremities, while 19 (43.20%) to left sided extremities. Majority of fractures 42 (95.5%) were close, while 2 (4.5%) fractures, one tibia and one forearm were open, Gustilo-Anderson type-II and type-I respectively. Femur fracture was commonest constituting about 61.40% (n=27) followed by tibia 20.45% (n=9), forearm bones 13.60% (n=6), while humerus fractures were least common 4.55% (n=2) in our series.

All 44 patients had union uneventfully, femur showed union within an average of 8.3 (range 4-10) weeks, tibia in 7.3 (range 6-10) weeks, forearm bones within 7 (range 6-8) weeks, and humerus in 7.5 (range 6-8) weeks.

All patients of femur/tibia fractures were allowed PWB ambulation with walker support from $2^{nd}/3^{rd}$ postoperative day, gradually progressing to FWB as union advanced within 6-8 weeks. 27 patients (femur -20, tibia -7) attained FWB walking within 6-8 weeks, while 8 patients (femur -6, tibia -2) attained FWB within 8-10 weeks. However one patient of femur fracture showed a bit rapid union and attained FWB within 4-6 weeks.

The commonest complication was pain at the insertion site with or without skin erosion. 5 patients (femur -3, tibia -1, forearm -1) had pain at insertion site, 2 of which suffered skin erosion. 1 femur patient had limb lengthening of 1.5 cm that needs to be assessed periodically till skeletal maturity to have an accurate assessment of LLD. 1 femur and 1 forearm patient showed restriction of knee flexion beyond 45^0, and 20^0 supination of forearm respectively, which however recovered with physiotherapy after hardware removal. No patient had delayed/non-union, sagittal/coronal/rotational mal-union, and deep infection.

On an average hardware from femur was removed at 7.8 (range 6-9) months, from tibia at 6.94 (range 6-9) months, from forearm bones at 4.8 (range 4-8) months, and from humerus at 3.5 (range 3-5) months.

Our results of ESIN of diaphyseal fractures of paediatric long bones in terms of time to union, time of PWB and FWB, rate of complications, and functional outcomes are comparable with the results of other series available.

Carey evaluated 25 patients of femur fractures, with a mean age of 8.5 years after ESIN.[18] Time to ambulation was 5.5 days as compared to 2-3 days in our series and LLD ranged -11 mm to +14 mm, while in our series one patient had lengthening of 1.5 cm. Average union time was 40 days as compared to 59 days (8.3 weeks) in our series. Similar to our series, there was no case of delayed/non-union/infection. Nails were removed at an average of 5 months vis-à-vis 7.8 months in our series. No patient had joint stiffness but in our series one patient had restriction of knee flexion beyond 45^0, which however recovered with physiotherapy after removal of hardware.

In Brien series of 16 tibia fractures, average union time was 9 weeks, while in our series 7.3 weeks, patients were not allowed PWB/FWB upto 5 weeks, while we allowed PWB from 2nd/3rd day.[19] Average time to nail removal was 6 months as compared to 6.94 months in our study. The author observed coronal angulation of not >6^0 in 6 patients and sagittal angulation of not >10^0 in 7 patients, which was not seen in any of our patients. Similar to our study, no patient showed delayed/nonunion, rotational malunion, physeal arrest, deep infection, joint stiffness, LLD, and re-fracture after nail removal.

In Manjappa series of 20 patients of forearm fractures, average time to union was 12 weeks compared to 7 weeks in our series.[20] 4 patients required mini open reduction compared to none in our series. All patients were given above elbow immobilization for 6 weeks compared to 4 weeks in our patients. 1 patient suffered re-fracture after nail removal, none in our series. 2 patients showed LLD leading to restriction of forearm rotation, but none of our patient showed LLD but 1 patient had 20^0 restriction of forearm supination, which however recovered with physiotherapy after nail removal. Similar to our series no patient showed delayed/nonunion/cross-union. Implant removed at an average of 3.5 months a little earlier than our patients (4.8 months). 15 (75%) patients showed excellent results, 3 (15%) had good results, and 2 (10%) had fair results according to Price et al. scoring as compared to 5 (83.3%) excellent and 1 (16.7%) good result in our patients.

CONCLUSION

The conservative treatment of paediatric long bone fractures is considered gold standard because of great ability of remodeling, but this treatment carries problems of loss of reduction, angulatory/rotational mal-alignment, longer hospital stay, prolonged immobilization keeping the child away from peer group and school. ESIN with TENs appears logical and safe to obviate these problems, as ESIN is least invasive, no/minimal blood loss, needs <1 cm incisions causing minimal scarring, doesn't violate fracture heamatoma/physis, works on trifocal buttressing providing sufficient axial/rotational stability, allows early PWB/FWB leading to independence earlier in terms of personal hygiene/toilet use with early social integration/return to school.

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