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Elastic stable intramedullary nailing for pediatric tibial shaft fractures: a prospective observational study of clinical, radiological and functional outcomes

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ABSTRACT

Background: Pediatric tibial shaft fractures are among the most common long-bone injuries in children. Although stable fractures can be managed conservatively, unstable or displaced fractures often require surgical stabilization. Elastic stable intramedullary nailing (ESIN) provides minimally invasive fixation while preserving fracture biology and allowing early mobilization. This study evaluated the clinical, radiological, and functional outcomes of ESIN in pediatric tibial shaft fractures.
Methods: This prospective observational study included 40 children aged 3–15 years with closed or Gustilo–Anderson grade I open tibial shaft fractures treated with ESIN at a tertiary care centre between October 2023 and November 2025. Patients were followed for 12 months. Outcome measures included radiological union using the modified radiographic union score for tibial fractures (mRUST), pain using the visual analogue scale (VAS), knee and ankle range of motion (ROM), time to weight-bearing, alignment, complications, and functional outcome using Flynn's criteria.
Results: The mean age was 10.7±2.9 years, and 72.5% of patients were male. Mean operative time was 60.5±9.5 minutes with mean blood loss of 20.8±7.3 ml. Radiological healing, pain, and functional outcomes improved significantly throughout follow-up (all $p<0.001$). Mean time to radiological union was 9.4±1.9 weeks, with full weight-bearing achieved at 10.7±2.1 weeks. At 12 months, 85% of patients had excellent and 15% had satisfactory outcomes according to Flynn's criteria. One patient (2.5%) developed a superficial wound infection; no non-union, malalignment, or significant limb-length discrepancy was observed.
Conclusions: ESIN is a safe, effective, and minimally invasive treatment for pediatric tibial shaft fractures, providing reliable fracture union, excellent functional recovery, and a low complication rate.

Keywords: Pediatric tibial shaft fracture, ESIN, Fracture union, Flynn's criteria, Functional outcome

INTRODUCTION

Pediatric tibial fractures account for approximately 15% of all long-bone fractures in children, making the tibia the second most commonly fractured long bone in the pediatric population.[1] These injuries predominantly affect school-age children between 6 and 14 years, with a clear male predominance, and most frequently arise from sports activities, road-traffic collisions, and torsional mechanisms.[2]

The distinctive biological properties of the immature skeleton — including a thicker and more vascular periosteum, greater cortical plasticity, and active physeal growth — confer both exceptional healing potential and particular vulnerability. Conservative management with closed reduction and long-leg casting remains appropriate

for minimally displaced or stable fractures; however, unstable, displaced, open, or comminuted injuries, and fractures in polytrauma settings, require surgical stabilisation.[1,3]

Elastic stable intramedullary nailing (ESIN), first described by Métaizeau in the 1980s, has emerged as the gold-standard minimally invasive technique for diaphyseal fractures in skeletally immature patients.[3] Titanium or stainless-steel nails inserted through small metaphyseal incisions provide three-point fixation and balanced elastic forces, stabilising the fracture while preserving periosteal vascularity and permitting early mobilisation.[4] Compared with rigid nailing, plating, and external fixation, ESIN offers shorter operative time, lower blood loss, reduced infection risk, and superior cosmetic results.[4,5]

Despite these advantages, prospective outcome data from tertiary-care centres serving resource-constrained tribal and semi-urban populations of India remain sparse. The present study aimed to evaluate the functional, clinical, and radiological outcomes of pediatric tibial shaft fractures treated with ESIN at a single tertiary centre in Gujarat.

METHODS

Study design and setting

This prospective observational study was conducted at the Department of Orthopaedics, Zydus Medical College and Hospital, Dahod (a 1034-bed tertiary referral centre with a 24/7 emergency service) from October 2023 to November 2025. Ethical approval was granted by the Institutional Ethics Committee (IEC; Enrollment No. R23150105000810004; October 2023). The study was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from the parent or legal guardian of every participant prior to enrolment.

Participants

Inclusion criteria

Children aged 3–15 years; closed tibial shaft fractures or Gustilo–Anderson grade I open tibial shaft fractures; willingness to undergo surgery and provide informed consent were included.

Exclusion criteria

Patients with Gustilo grade II or III open fractures; multiple ipsilateral injuries; pathological fractures; intra-articular extension; ASA status 5; neurovascular injury; epiphyseal fractures; known metabolic bone disease (osteogenesis imperfecta, congenital pseudarthrosis, or dysplasia); unwillingness to consent were excluded.

A consecutive sample of 40 patients fulfilling the inclusion criteria was enrolled.

Surgical technique

All procedures were performed under spinal anesthesia with the patient supine on a radiolucent table. Nail diameter was selected as 40% of the narrowest medullary canal diameter on pre-operative radiographs. Two nails of equal diameter were pre-bent and inserted antegradely through medial and lateral metaphyseal entry points, 1.5–2 cm distal to the proximal physis, under continuous fluoroscopic guidance. Fracture reduction was confirmed in two orthogonal planes. Nail ends were trimmed and bent to facilitate later retrieval. A post-operative below-knee splint was applied for two weeks, followed by a supervised physiotherapy protocol.

Outcome measures

Patients were assessed pre-operatively (baseline) and at 1, 3, 6, and 12 months post-operatively: radiological healing by mRUST score (range 4–12; union defined as score ≥10); pain by VAS (0–10); joint motion by knee and ankle ROM as a percentage of the uninjured contralateral side; functional outcome by Flynn's criteria (excellent/satisfactory/poor) at 12 months; weight-bearing milestones; alignment by coronal and sagittal angulation and LLD at final follow-up; and all complications throughout the study period.

Statistical analysis

Continuous variables are presented as mean±SD or median (IQR). Repeated-measures comparisons used Friedman's test. Between-group comparisons used the Mann–Whitney U test (open versus closed) and Kruskal–Wallis H test (fracture patterns). A two-tailed p value <0.05 was considered statistically significant. All analyses were performed using statistical package for the social sciences (SPSS) version 26.0 (IBM Corp., Armonk, NY, USA).

Sex and gender reporting

Sex was recorded as male or female at birth and is reported as a baseline demographic characteristic. The study did not assess gender identity. The influence of sex on outcomes was examined descriptively; formal subgroup analysis was not performed owing to sample-size limitations.

RESULTS

Demographic and fracture characteristics

Forty children were enrolled (Table 1). Mean age was 10.7±2.9 years (median 10.7; IQR 9.1–12.4) and males predominated (n=29; 72.5%). Sports-related injuries (37.5%) and road-traffic accidents (32.5%) accounted for 70% of cases. Middle-third fractures predominated (60%), with transverse (40%) and oblique (27.5%) patterns most common. Eighty percent of fractures were closed; 20% were Gustilo grade I open injuries.

Table 1: Patient demographics and fracture characteristics (n=40).

Category	N	%
Demographics		
Age (years)		
Mean±SD	10.7±2.9	—
Median (IQR)	10.7 (9.1–12.4)	—
Sex		
Male	29	72.5
Female	11	27.5
Side		
Right	18	45.0
Left	22	55.0
Mechanism of injury		
Sports	15	37.5
Road traffic accident	13	32.5
Twist/low-energy fall	7	17.5
Fall from height	5	12.5
Fracture location		
Middle third	24	60.0
Distal third	12	30.0
Proximal third	4	10.0
Fracture pattern		
Transverse	16	40.0
Oblique	11	27.5
Spiral	9	22.5
Comminuted	4	10.0
Fracture type		
Closed	32	80.0
Open (Gustilo grade I)	8	20.0

Operative characteristics

Mean operative time was 60.5±9.5 min (median 60; IQR 56–68) and mean blood loss was 20.8±7.3 ml (Table 2), confirming the minimally invasive character of the technique.

Radiological healing and functional recovery

The mRUST score increased progressively from 3.9±0.8 at baseline to 10.3±1.1 at 12 months (Friedman χ^2=160.00, p<0.001), indicating reliable callus formation across all follow-up intervals. Pain VAS declined from 6.5±1.2 to 1.2±1.3 at 12 months (Friedman χ^2=158.08, p<0.001). Knee ROM improved from 65.0±10.7% to 94.4±7.0% (Friedman χ^2=153.17, p<0.001) and ankle ROM from 60.5±8.1% to 94.5±6.3% (Friedman χ^2=151.63, p<0.001). Flynn functional score rose from 40.5±7.7% to 87.7±9.5% at 12 months (Friedman χ^2=157.99, p<0.001). All timepoint data are presented in Table 3.

Table 2: Operative metrics.

Variable	Mean±SD	Median (IQR)
Operative time (min)	60.5±9.5	60 (56–68)
Blood loss (ml)	20.8±7.3	20 (13–28)

Weight-bearing and union milestones

Partial weight-bearing commenced at 5.5±1.3 weeks; radiological union at 9.4±1.9 weeks; full weight-bearing at 10.7±2.1 weeks. Open Gustilo grade I fractures had slightly longer mean union times (9.0±2.2 versus 8.0±2.7 weeks), but this was not statistically significant (Mann–Whitney U=78.0, p=0.094). No significant difference in union time was observed across fracture patterns (Kruskal–Wallis H=2.33, p=0.506). Details are presented in Table 4.

Alignment and limb-length discrepancy

At final follow-up, mean coronal angulation was 1.7±1.1° and sagittal angulation was 2.0±1.1°. Mean LLD was 3.3±2.3 mm. No patient exceeded acceptable thresholds of >5° malalignment or >10 mm LLD (Table 5).

Complications and final outcome

Complications were rare; 39 of 40 patients (97.5%) experienced none. One patient (2.5%) developed a superficial wound infection at the nail entry site, which resolved with oral antibiotics.

By Flynn's criteria at 12 months, 34 patients (85%) were rated excellent and 6 (15%) satisfactory; no patient was rated poor (Table 6).

Table 3: Longitudinal outcome measures at each follow-up timepoint (all p<0.001 by Friedman's test).

Timepoint	mRUST, mean±SD	Pain VAS, mean±SD	Knee ROM%, mean±SD	Ankle ROM%, mean±SD	Flynn score%, mean±SD
Baseline	3.9±0.8	6.5±1.2	65.0±10.7	60.5±8.1	40.5±7.7
1 month	5.8±0.9	4.5±1.3	74.5±11.7	74.3±10.2	57.7±9.7
3 months	7.8±1.1	2.8±1.5	85.4±11.2	86.5±10.4	72.6±9.9
6 months	9.6±1.1	1.6±1.5	91.4±9.2	91.9±8.2	83.3±10.1
12 months	10.3±1.1	1.2±1.3	94.4±7.0	94.5±6.3	87.7±9.5

ROM: Range of motion; VAS: visual analogue scale; mRUST: modified radiological union score for tibial fractures

Table 4: Weight-bearing and union milestones.

Outcome/group	Mean±SD
Overall milestones	
Time to partial weight-bearing (weeks)	5.5±1.3
Time to radiological union (weeks)	9.4±1.9
Time to full weight-bearing (weeks)	10.7±2.1
Union time by injury type (Mann–Whitney U=78.0, p=0.094)	
Closed fractures (n=32)	8.0±2.7 weeks
Open fractures, Gustilo grade I (n=8)	9.0±2.2 weeks
Union time by fracture pattern (Kruskal–Wallis H=2.33, p=0.506)	
Transverse	11.6±1.9 weeks
Oblique	11.7±2.1 weeks
Spiral	10.5±1.9 weeks
Comminuted	11.5±1.2 weeks

Table 5: Alignment and limb-length discrepancy at final follow-up.

Measure	Mean±SD	Patients exceeding acceptable threshold
Coronal angulation (°)	1.7±1.1	>5°: 0 (0.0%)
Sagittal angulation (°)	2.0±1.1	>5°: 0 (0.0%)
LLD (mm)	3.3±2.3	>10 mm: 0 (0.0%)

Table 6: Complications and functional outcome by Flynn's criteria at 12 months.

Category	N	%
Complications		
None	39	97.5
Superficial wound infection (resolved with oral antibiotics)	1	2.5
Functional outcome — Flynn's criteria		
Excellent	34	85.0
Satisfactory	6	15.0
Poor	0	0.0

DISCUSSION

The present study evaluated ESIN outcomes in 40 pediatric patients with tibial shaft fractures at a tertiary centre serving the tribal belt of Gujarat, India. Our findings consistently align with established international evidence while contributing novel regional data for this under-represented population.

The observed male predominance (72.5%) and mean age of 10.7 years are consistent with demographic patterns reported by Pogorelić et al and Palmu et al who documented peak incidence among male children in late-primary-school age.[6,9] Sports injuries and road-traffic accidents comprised 70% of mechanisms, mirroring contemporary epidemiological data.[2,6]

Middle-third diaphyseal fractures (60%) and transverse or oblique patterns (67.5%) predominated, consistent with AO pediatric comprehensive classification studies.[7] Mean operative time (60.5 min) and blood loss (20.8 ml) compare favourably with series by Pennock et al and confirm ESIN's technical efficiency.[8]

Radiological union progressed significantly across all timepoints ($p<0.001$), reaching a mean mRUST of 10.3 at 12 months. Mean time to union was 9.4±1.9 weeks, within the 9–13-week range reported in systematic reviews.[10,12] The absence of a significant difference in union times across fracture patterns ($p=0.506$) supports the premise that ESIN provides stable fixation regardless of simple fracture morphology.[4,10]

Pain and functional recovery followed consistent upward trajectories, with knee and ankle ROM approaching normal values by six months. Flynn functional scores improved from 40.5% pre-operatively to 87.7% at 12 months — outcomes comparable to multicenter data.[12] Weight-bearing milestones are concordant with published series reporting partial weight-bearing at approximately 6 weeks following ESIN.[10]

Although Gustilo grade I open fractures showed marginally longer union times (9.0 versus 8.0 weeks), this difference was not significant ($p=0.094$), consistent with findings by Uludağ and Tosun.[4] No patient exceeded acceptable thresholds for malalignment or LLD, affirming the biomechanical reliability of three-point ESIN

fixation.[4,12] The 2.5% complication rate compares favourably with published rates and reflects the benefit of meticulous technique, appropriate nail sizing, and structured post-operative care.[11]

This study contributes prospective evidence from a resource-limited setting where ESIN's low cost, limited instrumentation requirements, and short hospital stay are particularly advantageous.

Limitations

Single-centre design and a sample of 40 patients limit statistical power and generalisability. The absence of a comparative arm precludes direct efficacy comparisons. Nutritional and activity-related confounders were not controlled. Future multicentre prospective trials are warranted.

CONCLUSION

ESIN is a safe, minimally invasive, and biologically compatible technique for unstable pediatric tibial shaft fractures. In this prospective cohort, the procedure delivered reliable radiological union within 10 weeks, excellent limb alignment, progressive restoration of joint motion, and a low complication rate. At 12 months, 100% of patients achieved excellent or satisfactory outcomes by Flynn's criteria, reinforcing ESIN as the preferred surgical option for diaphyseal tibial fractures in skeletally immature patients, including in resource-constrained settings.

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