RESEARCH PAPER

FUNCTIONAL AND RADIOLOGICAL OUTCOMES OF PEDIATRIC TIBIAL DIAPHYSEAL FRACTURES MANAGED WITH TITANIUM ELASTIC NAILING

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Abstract

Background: Tibial diaphyseal fractures are common long-bone injuries in children. Although most pediatric tibial fractures can be managed conservatively, unstable fractures may require operative stabilization. Titanium Elastic Nailing System (TENS) provides stable fixation while preserving the physis and allowing early mobilization.

Aim: To evaluate the functional and radiological outcomes of pediatric tibial diaphyseal fractures treated with Titanium Elastic Nailing System.

Materials and Methods: A prospective observational study was conducted in the Department of Orthopaedics, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, from May 2025 to February 2026. Thirty patients aged 5–17 years with tibial diaphyseal fractures fulfilling the predefined inclusion criteria were treated with TENS. Patients were assessed clinically and radiologically for fracture union, range of motion, duration of hospital stay, time to union, and postoperative complications. Functional outcome was assessed using Flynn's criteria. Data were analyzed using appropriate descriptive and inferential statistical methods, with $p<0.05$ considered statistically significant.

Results: Of the 30 patients, 22 (73.33%) were males and 8 (26.67%) were females. Road traffic accidents were the commonest mechanism of injury, accounting for 21 (70.00%) cases. Closed fractures constituted 21 (70.00%) cases, while 9 (30.00%) were open fractures. The middle third of the tibia was the most commonly involved site (63.33%). The mean duration of surgery was 49 minutes, and 28 (93.33%) patients had a hospital stay of less than 7 days. Fracture union occurred within 10–12 weeks in 26 (86.67%) patients, with a mean union time of approximately 12 weeks. At 24 weeks, 28 (93.33%) patients achieved full range of motion of the knee and ankle, while 2 (6.67%) had mild restriction. According to Flynn's criteria, 25 (83.33%) patients had an excellent outcome and 4 (13.33%) had a satisfactory outcome. The most frequent complications were malalignment, nail-site irritation, and superficial infection.

Conclusion: TENS provides satisfactory functional and radiological outcomes in pediatric tibial diaphyseal fractures. It offers stable fixation, early mobilization, relatively short hospital stay, and a favorable complication profile. TENS can therefore be considered an effective treatment option for appropriately selected unstable tibial diaphyseal fractures in children.

Keywords: Tibial diaphyseal fracture; Children; Pediatric fractures; Titanium elastic nail; TENS; Functional outcome; Elastic stable intramedullary nailing.

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Introduction

Tibial shaft fractures are among the common long-bone fractures encountered in the pediatric population. Because of the excellent healing potential and remodeling capacity of children, most stable tibial diaphyseal fractures can be successfully managed by closed reduction and immobilization in a cast, which remains the standard initial treatment. However, maintaining acceptable alignment may be difficult in fractures associated with significant shortening, angulation, malrotation, marked displacement, or instability. Operative stabilization may therefore be required in selected patients, particularly in the presence of open fractures, polytrauma, compartment syndrome, associated neurovascular injury, or severe soft-tissue compromise.1,2

Historically, unstable pediatric tibial shaft fractures requiring surgical fixation were managed using external fixation or plate-and-screw constructs. Although these methods can provide satisfactory fracture stabilization, they are associated with complications such as pin-tract infection, soft-tissue irritation, refracture, scarring, and, in some circumstances, delayed union or malunion.3,4 Rigid reamed intramedullary nailing is an established treatment for tibial shaft fractures in skeletally mature individuals; however, its use in children with open proximal tibial physes is limited because of the potential risk of physeal injury.5 Consequently, there has been increasing interest in minimally invasive fixation methods that provide adequate stability while preserving the growth plates.

Elastic stable intramedullary nailing (ESIN) has gained widespread acceptance in the management of long-bone fractures in skeletally immature patients. The technique uses flexible, pre-contoured nails inserted through metaphyseal entry points, allowing fracture stabilization while avoiding the physis. Its major advantages include closed or minimally invasive insertion, preservation of the fracture hematoma, reduced soft-tissue disruption, and early mobilization.6,7 The effectiveness of titanium elastic nails has been extensively demonstrated in pediatric femoral fractures, establishing the technique as a reliable method of flexible intramedullary fixation in children.

The application of titanium elastic nails (TENs) to pediatric tibial shaft fractures has subsequently gained popularity, particularly for unstable fractures that cannot be adequately maintained by conservative treatment. Several studies have reported satisfactory union rates, acceptable alignment, early weight bearing, and relatively low complication rates following TEN fixation of pediatric tibial fractures.8,9 The elastic nails function as load-sharing internal splints, providing sufficient stability while permitting controlled micromotion at the fracture site, which promotes secondary bone healing.10 In addition, the technique generally avoids prolonged postoperative casting and reduces the need for repeated manipulation to maintain axial alignment.

Clinical studies have demonstrated favorable outcomes following TEN fixation of pediatric tibial shaft fractures. Sankar et al. reported reliable fracture healing with acceptable alignment and a low incidence of major complications, supporting the use of titanium elastic nails for unstable tibial fractures in children.11 Similarly, subsequent studies have demonstrated good functional and radiological outcomes, with most children achieving satisfactory or excellent results according to established functional scoring systems.12,13 Nevertheless, complications such as nail prominence, skin irritation, superficial infection, delayed union, malalignment, limb-length discrepancy, and refracture may occur and require careful postoperative monitoring.14

Considering the advantages of minimally invasive fixation, preservation of the proximal tibial physis, early mobilization, and satisfactory fracture healing, TEN fixation represents an important treatment option for appropriately selected pediatric tibial diaphyseal fractures. The present study was therefore undertaken to evaluate the functional outcome of pediatric tibial diaphyseal fractures treated with titanium elastic nailing system, with particular emphasis on fracture union, postoperative alignment, range of motion, complications, and overall functional recovery.

Aim

To evaluate the functional outcome of pediatric tibial diaphyseal fractures treated with Titanium Elastic Nailing System (TENS).

Objectives

To assess the functional outcome following TENS fixation of tibial diaphyseal fractures in children.

To evaluate the time to radiological fracture union following TENS fixation.

To assess the postoperative alignment and range of motion of the affected limb.

To evaluate the time to mobilization and return to normal activities after surgery.

Materials and Methods

This prospective observational study was conducted in the Department of Orthopaedics, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, from May 2025 to February 2026. The study included pediatric patients with tibial diaphyseal fractures who fulfilled the predefined inclusion and exclusion criteria and were treated with Titanium Elastic Nailing System (TENS). Patients aged 5–17 years with closed tibial diaphyseal fractures and open tibial diaphyseal fractures classified as Gustilo-Anderson grade I, II, or IIIA were included. Patients with malunited or non-united tibial fractures, those who were medically unfit for surgery, Gustilo-Anderson type

IIIB or IIIC open fractures, patients younger than 5 years or older than 17 years, and those with pathological fractures were excluded from the study. A detailed history was obtained from all patients, with particular emphasis on age, sex, mechanism of injury, duration between injury and presentation, and the interval between injury and definitive treatment. A thorough clinical examination was performed, including general examination, local examination of the injured limb, assessment of distal neurovascular status, systemic examination, and evaluation for associated injuries such as head, chest, abdominal or visceral injuries and other skeletal injuries. All relevant clinical findings, treatment details, postoperative observations, and follow-up findings were documented in a structured study proforma. Radiological assessment was performed using anteroposterior and lateral radiographs of the affected tibia. The diagnosis and fracture characteristics were established based on the combined clinical and radiological assessment.

All patients underwent routine preoperative evaluation and optimization before surgery. Whenever clinically feasible, definitive surgical treatment was performed within 48 hours of injury. Patients were kept fasting overnight before surgery, while emergency cases were kept nil per oral for a minimum of 6–8 hours according to anesthetic requirements. Appropriate blood grouping and cross-matching were performed, and adequate blood was kept available when considered necessary. Patient identification was confirmed using name, age, sex, registration number, and ward details. The operative limb was prepared and draped under strict aseptic precautions. A third-generation cephalosporin was administered intravenously approximately one hour before surgery as perioperative antibiotic prophylaxis. TENS fixation was performed under either general or spinal anesthesia according to the patient's age, clinical condition, and anesthetic assessment.

For surgical fixation, the required instruments included a knife, bone-entry awl, titanium elastic nails, nail inserter with key, hammer, and nail cutter. Titanium elastic nails ranging from 1.5 to 4 mm in diameter were used according to the patient's age, fracture characteristics, and medullary canal dimensions. Patients were positioned supine on a radiolucent operating table with a support beneath the knee. A tourniquet was applied to the upper thigh but was inflated only when required. The C-arm image intensifier was positioned to obtain appropriate anteroposterior and lateral fluoroscopic views. The fracture site, proximal tibial physis, and nail entry points were identified under fluoroscopy. The entry point was made approximately 1.5–2 cm distal to the proximal tibial physis on the anteroposterior view and centrally positioned on the lateral view, with care taken to avoid injury to the tibial tubercle apophysis.

Two appropriately sized nails were selected, with the aim of achieving adequate canal occupancy and balanced elastic fixation. The nail diameter was approximately 40% of the narrowest diameter of the medullary canal, assessed on anteroposterior and lateral radiographs. The nail length was determined fluoroscopically by placing the selected nail alongside the tibia. A small longitudinal incision was made over the proximal tibial metaphysis. Using fluoroscopic guidance, an entry hole was created with an awl or drill approximately 0.5 mm larger than the selected nail, while avoiding penetration of the opposite cortex or proximal tibial physis. The nails were prebent at the tip to approximately 45° to facilitate insertion and fracture reduction. The entire nail was contoured into a gentle curve to provide appropriate three-point fixation and optimal stability. The prebent nails were introduced in an antegrade manner from opposite sides of the proximal tibia and advanced along the medullary canal under fluoroscopic guidance. After achieving fracture reduction, the nails were advanced across the fracture site into the distal fragment. The final position and fracture alignment were confirmed using anteroposterior and lateral fluoroscopic images, and the nail ends were appropriately cut and positioned to minimize soft-tissue irritation.

Postoperative Assessment and Follow-up

Postoperatively, patients were monitored for pain, wound condition, neurovascular status, infection, compartment syndrome, and other early complications. Radiographs were obtained during follow-up to assess fracture alignment and progression of union. Patients were followed clinically and radiologically at predetermined intervals until satisfactory fracture union and functional recovery were achieved. Functional outcome was assessed using an appropriate validated pediatric functional assessment scale, along with evaluation of pain, range of motion, weight-bearing ability, return to routine activities, fracture union, residual deformity, and postoperative complications. Particular attention was given to complications related to TENS, including nail prominence, skin irritation, infection, delayed union, malunion, limb-length discrepancy, and refracture.

Statistical Analysis

The collected data were entered into a Microsoft Excel spreadsheet and analyzed using appropriate statistical software. Continuous variables such as age, duration of hospital stay, time to fracture union, and time to return to full weight bearing were expressed as mean ± standard deviation or median with interquartile range, depending on the distribution of the data. Categorical variables such as sex, fracture type, mechanism of injury, fracture location, complications, and functional outcome categories were presented as frequencies and percentages. The normality of continuous variables

was assessed using an appropriate test such as the Shapiro–Wilk test. For comparison of continuous variables between two groups, an independent-samples t test or Mann–Whitney U test was used as appropriate. Categorical variables were compared using the chi-square test or Fisher's exact test when required. For comparison of functional outcomes across more than two groups, one-way analysis of variance or the Kruskal–Wallis test was used as appropriate. Correlation between relevant clinical or radiological parameters and functional outcome was assessed using Pearson or Spearman correlation analysis. A multivariable logistic regression analysis may be performed to identify independent factors associated with an unfavorable functional outcome, depending on the sample size and number of outcome events. A p-value <0.05 was considered statistically significant.

Result:

Table 1: Demographic data

Age Group (in years)	Numbers of patients	%
5-9	9	30.00
10-13	11	36.67
14-17	10	33.33
Gender		
Male	**22**	73.33
Female	**8**	26.67
Mode of injury		
RTA	**21**	70.00
Self-fall	**2**	6.67
Sport related injury	**4**	13.33
Fall from Height	**3**	10.00
Side affected		
Right	**17**	56.67
Left	**13**	43.33

In our study 30 % of patients (9 out of 30) were age 5 to 9 years, 36.67% of patients (11 out of 30) were between 10 to 13 years of age. In our study 73.33 % of patients (22 out of 30) were male and 26.67% of patients (8 out of 30) were female. In our study majority (70%) of patients (21 out of 30) had injury due to road traffic accident and 13.33% (4 out of 30) due to sports related injury. In our study, right side 56.67 % (17 out of 30) was involved more than left side 43.33% (13 out of 30).

Table 2: Character, level and pattern of fracture

Character of fracture	Number of patients	%
Closed	21	70.00
Open GA Type 1	4	13.33
Open GA Type II	5	16.67
Open GA Type III	0	0.00
Level of fracture		
Proximal	1	3.33
Mid Shaft	19	63.33
Distal Shaft	10	33.33
Pattern of fracture		
Transverse	17	56.67
Short oblique	12	40.00
Long oblique	0	0.00
Spiral	1	3.33
Comminuted	0	0.00

In our study, closed fractures were 70 % (21 out of 30) and Open fractures GA Type II were 16.67% (5 out of 30). In our study, middle shaft fractures were 63.33 % (19 out of 30), distal third fracture were 33.33 % (10 out of 30). In our study, transverse fractures cases were 56.67% (17 out of 30), short oblique fracture cases were 40.00 % (12 out of 30).

Table 3: Duration of surgery (min), duration of hospital and time for union

Duration of surgery (min)	Number of patients	%
< 30	3	10.00
31-60	22	73.33
61-90	5	16.67
Duration of Hospital Stay (Days)		
< 5	13	43.33

6-7	15	50.00
> 8	2	6.67
Time for Full Union		
10 - 12 weeks	26	86.67
13 -15 weeks	2	6.67
> 15 weeks	2	6.67

In our study average duration of surgery was 49 minutes. The duration of stay in the hospital was < 7 days for 93.33% (28 out of 30) patients, 8-11 days for 2 patients. In our study most of cases (86.67%) were united upto 12 weeks of surgery. Only 1 case of delay union was noted. The mean time for union was 12 weeks.

Table 4: Range of Movement at 24 Weeks

Range of Movement at 24 Weeks	**Number of patients**	**%**
Full range	28	93.33
Mild restiction	2	6.67
Moderate restriction	0	0.00
Severe restiction	0	0.00
Total	**30**	100.00

In our study full range of motion was present at knee and ankle joint after surgery at 24 weeks in 93.33% patient in our study. 2 patients (6.67%) had mild restriction in ankle dorsiflexion and Knee flexion.

Table 5: Complications

Complications	**No. of cases**	**Percentage**
Nail site irritation	2	6.67
Pain	0	0.00
Infection		
Superficial	2	6.67
Deep	1	3.33
Recurrent fracture	0	0.00
Delayed union and nonunion	1	3.33
Limb lengthening		
<2 cm	1	3.33
>2 cm	0	0.00
Limb shortening		
<2 cm	1	3.33
>2 cm	0	0.00
Nail back out	0	0.00
Malalignment		
a. Varus angulation	1	3.33

b. Valgus angulation	2	6.67
c. Anterior angulation	2	6.67
d. Posterior angulation	0	0.00
e. Rotational malalignment	1	3.33
Bursa at the tip of the nail	1	3.33
Sinking of nail into the medullary canals	0	0.00

In our study infection (Superficial and Deep) was seen in 3 cases (9.97%). Limb length inequality 2 (6.67%) cases, delayed union 1 (3.33%) case, nail irritation was present in 2 (6.2%) cases, malalignment in 6 (19.9%) cases and bursa at the tip of the nail in 1 (3.33%) case.

Table 6: Outcome according to Flynn's criteria

Outcome according to Flynn's criteria	Number of patients	%
Excellent	25	83.33
Satisfactory	4	13.33
Poor	1	3.33
Total	**30**	100.00

In our study, the final outcome was excellent in 83.33% (25 out of 30), satisfactory or good in 13.3 % (4 out of 30) cases and poor outcome was reported in 1 case (3.33%) only.

Discussion

In the present study, 30 pediatric patients with tibial diaphyseal fractures treated with Titanium Elastic Nailing System (TENS) were evaluated. The age distribution showed that 30.00% of patients were 5–9 years, 36.67% were 10–13 years, and 33.33% were 14–17 years. There was a male predominance, with males accounting for 73.33% of cases. Road traffic accidents were the commonest mechanism of injury (70.00%), followed by sports-related injuries (13.33%). The right tibia was involved slightly more frequently than the left. These findings are consistent with the pediatric tibial fracture literature, where trauma-related injuries and male predominance are commonly reported. Flexible intramedullary nailing is particularly useful in unstable fractures in older children and adolescents where maintaining alignment by conservative treatment may be difficult.

Regarding fracture characteristics, 70.00% of fractures in our series were closed, while 30.00% were open fractures, including Gustilo-Anderson type I and II injuries. The middle third was the most frequently involved level (63.33%), followed by the distal third (33.33%). Transverse fractures constituted the majority (56.67%), followed by short-oblique fractures (40.00%). The predominance of mid-shaft fractures is clinically relevant because the flexible intramedullary technique provides effective three-point fixation and helps maintain alignment while preserving the fracture hematoma. Previous studies have demonstrated that flexible titanium nails can reliably stabilize unstable pediatric tibial shaft fractures with high rates of union.

The mean operative duration in our study was 49 minutes, with 73.33% of procedures completed within 31–60 minutes. Early mobilization and relatively short hospitalization are important advantages of minimally invasive elastic nailing. In our series, 93.33% of patients were discharged within 7 days, indicating satisfactory early postoperative recovery. Fracture union occurred within 10–12 weeks in 86.67% of patients, with a mean union time of approximately 12 weeks. Sankar et al. reported complete healing in all 19 patients treated with titanium elastic nails, with a mean union time of 11 weeks. O'Brien et al. similarly reported union in all unstable pediatric tibial fractures treated with flexible titanium nails, although open fractures required longer healing times than closed injuries. Thus, the union rate and healing period observed in

our study are comparable with previously published results.

At 24 weeks, 93.33% of our patients had full range of motion at the knee and ankle, while only 6.67% had mild restriction. This favorable functional recovery may be attributed to stable fixation, limited soft-tissue disruption, and early mobilization permitted by TENS. In the present study, according to Flynn's criteria, 83.33% of patients achieved an excellent outcome and 4 patients achieved a satisfactory outcome. Sankar et al. reported 12 excellent, 6 satisfactory, and 1 poor outcome among 19 patients using the same classification, supporting the favorable functional results achievable with TENS.

Complications in our study were generally minor and manageable. Nail-site irritation occurred in 6.67%, superficial infection in 6.67%, deep infection in 3.33%, delayed union in 3.33%, and bursa formation at the nail tip in 3.33%. Malalignment was noted in 19.9%, although most deformities were mild. No recurrent fracture or nail back-out was observed. Previous studies have also identified nail-site irritation and angular deformity among the principal complications of flexible tibial nailing. Sankar et al. reported nail-entry-site irritation in 26% of patients, while Goodwin et al. reported complications in 26% of their patients, although none required repeat surgery. Overall, our findings support TENS as an effective minimally invasive treatment for appropriately selected pediatric tibial diaphyseal fractures, providing reliable union, good functional recovery, early rehabilitation, and an acceptable complication profile.

Conclusion

Titanium Elastic Nailing System (TENS) is an effective and minimally invasive method for the management of appropriately selected tibial diaphyseal fractures in children. In our study of 30 patients, the majority achieved fracture union within 10–12 weeks, with a mean union time of approximately 12 weeks. At 24 weeks, 93.33% of patients had full range of motion of the knee and ankle. According to Flynn's criteria, 83.33% of patients achieved an excellent functional outcome, while the remaining patients had satisfactory outcomes.

The complication rate was acceptable, with most complications being minor and manageable. No cases of refracture or nail back-out were observed. The technique provided stable fixation, allowed early mobilization, facilitated relatively early hospital discharge, and preserved the advantages of minimally invasive surgery.

Overall, TENS provides satisfactory functional and radiological outcomes with an acceptable complication profile and can be considered a reliable treatment option for unstable pediatric tibial diaphyseal fractures, particularly when conservative management is unable to maintain acceptable alignment.

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