

Early Mobilization with Mechanical Axis Preservation: A Prospective Outcome Analysis of Titanium Elastic Nailing in Femoral Shaft Fractures of School-Aged Children

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Learning Point of the Article:

Titanium elastic nailing system (TENS) provides stable fixation with mechanical axis preservation in children with femur shaft fracture in school-aged children irrespective of fracture pattern.

Abstract

Introduction: Pediatric femoral shaft fractures are one of the commonest injuries in early childhood and school-going children, with operative management increasing preferred in the age group of 6–13 years. The titanium elastic nailing system (TENS) is the most preferred modality in this age group, providing stable fixation and biological preservation; however, its effect on mechanical axis alignment and early functional outcome needs evaluation. In this study, we aim to analyze the effect of femur shaft fractures being managed by TENS on the mechanical axis of the lower limb and its effect on the functional outcome of the patients after a short immobilization period of 2 weeks.

Materials and Methods: A prospective observational study was conducted at Baba Raghav Das Medical College, Gorakhpur between 2023 and 2025, including 32 children aged 6–13 years with femoral diaphyseal fracture undergoing TENS (excluding Gustillo-Anderson type IIIB/IIIC Injuries). Regular follow-up was done at 2, 6, and 12 weeks, and functional and radiological outcomes and mechanical alignment were recorded at 12 weeks using Flynn scoring criteria and orthoscanogram, respectively.

Results: Our study group had a mean age of 9.66 ± 2.25 years, with a higher male predilection (71.9%) and road traffic accident (43.8%) being the common mode of injury. We observed radiological union in all the patients with a mean union time of 10.88 ± 0.9 weeks, with no significant malalignment with mean medial proximal tibial angle and lateral distal femoral angle within an acceptable range, even after a short immobilization period. We observed a mean knee flexion of $112.7^\circ \pm 13.7^\circ$ at 12 weeks follow-up, with 81.2% of patients having excellent and the remaining 18.8% having satisfactory outcome with no poor results.

Conclusion: TENS is a safe, minimally invasive, alignment-preserving modality which provides stable fixation, excellent short-term outcomes with minimal complications in 6–13 years age group, irrespective of age, gender, or fracture type.

Keywords: Pediatric femur shaft fracture, titanium elastic nailing system, elastic stable intramedullary nailing, mechanical axis alignment, functional outcome (Flynn criteria).

Introduction

Pediatric femur shaft fractures are one of the common injuries with an annual incidence estimated at 20–25/100,000 children in India [1], usually occurring in early childhood (1–3 years)

during transition from weak woven bone to strong lamellar bone or in adolescent age due to high-energy trauma with a 2.6 times higher predilection in males [2]. Although the etiology of the fracture varies with the age of the child, the most common cause

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Author's Photo Gallery



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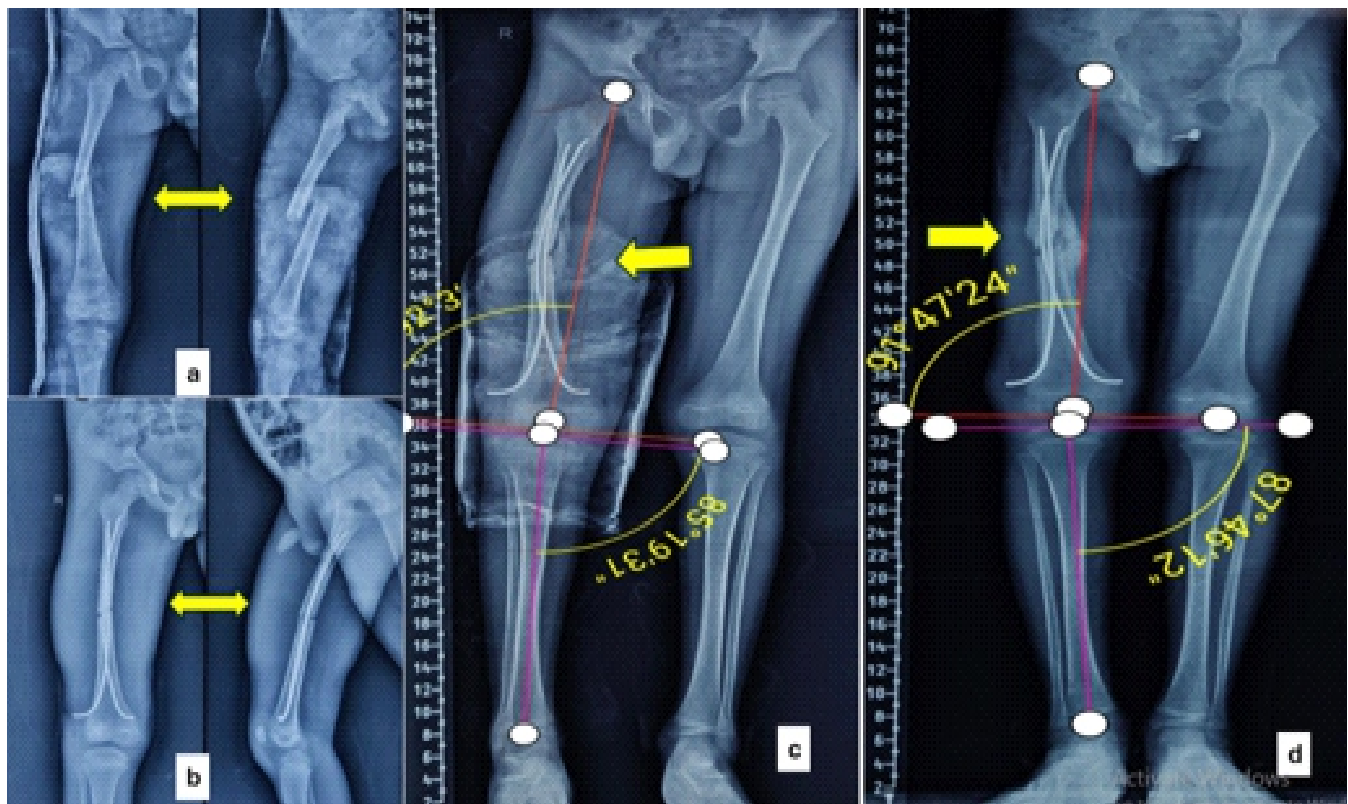


Figure 1: Example case: (a) Plain pre-operative anteroposterior (AP) and lateral view radiograph of a 9-year-old male child sustaining right femoral fracture (transverse type) following a fall from bed while playing. (b) Immediate post-operative X-ray AP and lateral views of the femur shaft after titanium elastic nailing system. (c) 8-week post-operative orthoscanogram showing callus formation (arrow marked). (d) 12-week post-operative orthoscanogram showing fracture union and findings consistent with approximately 2° of residual femoral varus deformity with no limb length discrepancy.

of femur shaft fractures in children is a fall from height and road traffic accidents [3]. However, child abuse is still one of the commonest causes of these fractures in children <18 months of age, as reported by Coffey et al. [4]. Management modalities of these fractures in <5 years of age include Hip spica application and interlocking nailing in adolescent over 15 years of age. Although the superiority of one particular modality has still not been established for management of these fractures in 5–15 years age group; however, evidence from multiple studies has favored the use of the titanium elastic nailing system (TENS) with favorable outcomes allowing early mobilization as reported amongst school-going age group [5,6,7].

TENS as a fixation method provides rotational stability and allows micromotion, leading to early fracture union, providing high patient satisfaction; however, a high complication rate of 60% have been reported in the studies, which are primarily due to poor patient selection, improper surgical techniques, and post-operative management protocols [8].

Most of the studies reported employ various post-operative immobilization techniques, including hip spica cast, knee immobilizer, above knee cast, hip knee ankle foot orthosis and Thomas splints for a variable period ranging from 2 to 6 weeks. These studies also mainly focus on fracture union,

complications, and functional outcome after TENS Nailing of pediatric femur shaft fracture, but its effect on the mechanical axis of the lower limb is scarcely reported. With our study, we aim to analyze the effect of femur shaft fractures being managed by TENS on the mechanical axis of the lower limb and its effect on the functional outcome of the patients after a short immobilization span of 2 weeks in a above knee plaster of Paris (POP) slab.

Materials and Methods

An observational prospective study was conducted in the Department of Orthopaedics, Baba Raghav Das Medical College between 2023 and 2025 after obtaining Institutional

Parameter	Excellent result	Satisfactory	Poor result
Length discrepancy	<1.0 cm	<2.0 cm	>2.0 cm
Malalignment	≤5°	>5–10°	>10°
Pain	No	No	No
Complications	None	Minor and resolved	Major and/or residual morbidity



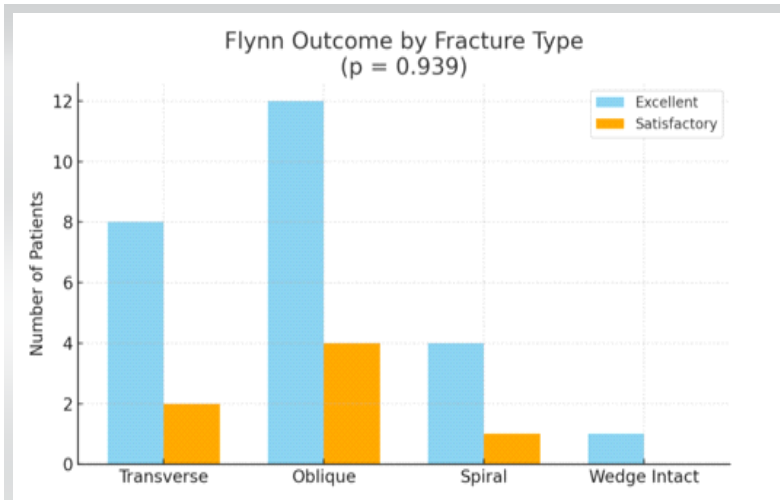


Figure 2: Bar chart showing the relationship between functional outcomes based on fracture pattern.

Ethics Committee approval (S. No.- 232/IHEC/2025), including 32 patients of 6–13 years age group with a femur shaft fracture (except Gustilo Andersons type IIIB and IIIC injuries) after informed parental consent. After pre-operative blood investigations and radiological investigations, including anteroposterior and Lateral views of full-length femur radiographs (for pre-operative planning of implant size calculation to achieve approximately 80% of canal diameter and location of pre-bending distance), after anesthetic fitness with appropriate anesthesia, patients were placed on the fracture table. Fracture reduction was achieved under fluoroscopy guidance, and patients were prepared and draped for the TENS nailing.

Under fluoroscopy guidance, 1–2 cm longitudinal skin incision was made over the lateral and medial aspect of the distal femur, starting 2 cm proximal to the distal femoral epiphyseal plate. The entry was made using bone-awl and two appropriate size, adequately pre-bent TENS nail was introduced from the lateral and medial aspect of the distal femur till the fracture line. After anatomical or near anatomical reduction under C-Arm, the TENS nails were subsequently introduced in a retrograde manner with a rotatory motion and gentle tap till greater trochanter and femoral neck, respectively. Postoperatively, patients were maintained in above knee POP Slab for 2 weeks till suture removal, along with non-weight-bearing gait with walker. Active and passive knee range of motion was started after 2 weeks, and Non-weight-bearing gait was continued till 6 weeks, followed by partial weight-bearing. Full weight-bearing was permitted after confirmation of radiological union at 10–12 weeks.

Patients were clinico-radiologically followed during this period at 2, 6, and 12 weeks, and mechanical axis measurement was performed using orthoscannogram at 6 and 12-week follow-up (Fig. 1). Functional outcome was assessed using the Flynn scoring system (Table 1) at the 12-week follow-up.

Statistical analysis was performed using IBM Statistical Package for the Social Sciences 28 (NY, USA) Software. The normal distribution suitability was performed using Shapiro–Wilk/Kolmogorov–Smirnov test. Categorical variables were expressed as frequency and percentage, while continuous variables were expressed as mean \pm standard deviation. The comparison among groups was done using Mann–Whitney U test and One-way Analysis of Variance (ANOVA) test, wherever applicable. A $P < 0.05$ was considered significant.

Results

Demographics

Out of 32 patients, 23 patients (71.9%) were male, with 9–11 years being the most common age group (13 patients; 40.6%), with a mean age of 9.66 ± 2.25 years. Road traffic accidents were the most common mode of injury occurring in 43.8% (14 patients), followed by a fall from height in 31.4% (10 patients). The majority of the patients of our study population had an oblique type fracture pattern (16 patients; 50%), followed by a transverse fracture in 10 patients (31.3%), a spiral fracture in 5

Table 2: Demographics and their effect on functional outcome

Categories	Number of patients ($n=32$) (%)	P -value*
Age groups	6–8 Years - 10 (31.3)	0.235
	9–11 Years - 13 (40.6)	
	12–13 Years - 9 (28.1)	
Gender	Male - 23 (71.9)	0.495
	Female - 9 (28.1)	
Fracture pattern	Transverse - 10 (31.3)	0.873
	Oblique - 16 (60)	
	Spiral - 5 (15.6)	
	Wedge impact - 1 (3.1)	
Mode of injury	Road traffic accident - 14 (43.8)	0.958
	Fall from height - 10 (31.4)	
	Fall from bicycle - 6 (18.8)	
	Fall on ground - 2 (6.2)	

(*)- Mann–Whitney U Test, $P < 0.05$ is Significant

Table 3: Outcome-knee range of motion and functional outcome based on Flynn scoring criteria

Flynn scoring criteria		
Knee range of motion	<100°- 12 Patients (37.4%)	
Mean range of motion- (112.7° ± 13.7°)	100–120°- 10 Patients (31.3%)	
	>120°- 10 Patients (31.3%)	
Flynn scoring criteria		
Outcome	Excellent (n=26)	Satisfactory (n=6)
Limb length discrepancy (cm)		
<1.0	26	5
<2.0	0	1
>2.0	0	0
Malalignment (Varus/valgus)		
≤5°	26	5
>5–10°	0	1
>10°	0	0
Pain		
Absent	26	6
Present	0	0
Complications		
Absent	26	0
Mild	0	6
Major complication	0	0

patients (15.6%), and an intact wedge pattern in one patient (3.1%).

Outcome

At 12 weeks follow-up, clinically majority of the patients were found to have knee flexion of 100–130° with the mean knee flexion of 112.7° ± 13.7° with no significant effect of fracture pattern ($P = 0.888$; One-way ANOVA test). The functional outcome based on Flynn scoring system showed 81.2% (26 patients) of having excellent outcome, followed by 6 patients (18.8%) with a satisfactory outcome. However, the outcome was not found to be significantly associated with different age groups, gender, and fracture pattern ($P = 0.235, 0.495, 0.873$, respectively; Mann–Whitney U test) (Table 2 and Fig. 2).

Radiological assessment at 12 weeks showed union in all the patients of our study, with a time of union ranging from 9 to 12 weeks, with a mean union of 10.88 ± 0.9 weeks, with no significant difference among different fracture patterns ($P = 0.203$; One-way ANOVA test). The mean medial proximal tibial angle (mPTA) was found to be 87.5° ± 2.1° while the mean lateral distal femoral angle (LDFA) was 87.9° ± 3.5° with no significant association noted with the fracture pattern ($P = 0.713$ and 0.823, respectively; One-way ANOVA test). No significant malalignment was noted among our study participants at the end of 12 weeks, and only one patient having shortening of the affected lower limb by approximately 2 cm.

No further incidences of Non-union, fixation failure, and persistent pain were observed (Table 3).

Discussion

Our study included 32 patients aged 6–13 years with femoral diaphyseal fractures being managed by TENS, which is the most preferred modality of fracture management in this age group, as they provide stable fixation while preserving both biology and growth potential. The demographic distribution of our study group were comparable to study groups of Flynn et al., Mann et al., Ligier et al. and others [5,9,10,11,12], where they had included patients with mean age ranging from 8.5 to 12.7 years with road traffic accidents as major mode of injury similar to mean age of 9.66 ± 2.25 years from our study group. Our study group also had 2.5 times more predilection towards school-aged boys due to higher outdoor activity and increased risk of trauma, which closely mimicked findings of Hedlund and Lindgren [3].

Fracture union was noted amongst all the patient of our study population with time of union ranging from 9 to 12 weeks with a mean union time of 10.88 ± 0.9 weeks which was comparable to union time of 8–12 weeks as reported in studies by Ansari et al., Bhuyan and Mohan Singh, Mishra et al. and others [9,10,13,14,15,16,17]. In accordance with a comparative study by Sahu and Goswamy [18], we also did not observe a significant difference in the union time among different fracture patterns ($P = 0.203$), emphasizing the importance of proper technique with appropriately sized, pre-bent nail as used in our study in providing effective stability irrespective of fracture pattern. Further, the absence of non-union or delayed union emphasizes on the advantage of using TENS nail in preserving biology at the fracture site.

Maintenance of alignment remains pivotal in determining long-term functional outcome in pediatric femoral shaft fractures. In accordance with the findings of a meta-analysis by Imam et al. and Kayaokay and Aktuglu [19,20], the radiological parameters such as mean mPTA (87.5° ± 2.1°) and mean LDFA (87.9° ± 3.5°) of our study group with short immobilization period of 2 weeks in above knee POP slab, remained within acceptable limits with no clinically significant malalignment irrespective of fracture pattern and only one patient reporting shortening of approximately 2 cm at 12 weeks of follow-up. These findings further affirm superior coronal and sagittal alignment, along with clinically insignificant limb length discrepancy (LLD) with TENS when compared with Conservative management when used with proper technique. However, inter-observer and intra-observer variability assessment and rotational malalignment were not included in this study.



Table 4: Comparison table of literature review with our study on the titanium elastic nailing system of pediatric femur shaft fractures

Study	Mean union time (weeks)	Functional outcome (Flynn's criteria)	Mean knee ROM	Reported complications
Ansari <i>et al.</i> [13]	10.1 weeks	>90% Excellent	>110° in majority	Nail prominence, minor LLD
Bhuyan and Mohan Singh [14]	~9 weeks	Predominantly excellent/Good	>110°	Superficial infection, irritation
Kawalkar and Badole [15]	~9 weeks	Majority excellent	Good ROM restoration	Minor angular deformity
Mishra <i>et al.</i> [16]	9.5 weeks	High excellent/Good rate	>110°	Mild LLD, superficial infection
Flynn <i>et al.</i> [5]	8–10 weeks	85–95% Excellent	Near full ROM	Nail prominence, rare malunion
Pandor <i>et al.</i> [22]	Mean union time: 7 weeks	Excellent: 24; Satisfactory: 5; Poor: 1 (<i>n</i> =30)	Functional ROM by mean 8 weeks	Varus (1), irritation (3), LLD (2)
Kayaokay and Aktuglu [20]	Mean union time 9.2±2.2 weeks	Excellent: 12; Satisfactory: 14; Poor: 4 (<i>n</i> =30)	Good ROM restoration	8 cases with LLD of 1–2 cm Varus angulation in 16 cases
Present study	10.88±0.9 weeks	81.2% Excellent, 18.8% satisfactory No poor outcome	112.7°±13.7°	One case 2 cm shortening; no non-union, infections, fixation failure
ROM: Range of motion, LLD: Limb length discrepancy				

Functionally, at 12-week follow-up, the majority of the patients had achieved a knee range of motion of 100–130° and a mean of 112.7° ± 13.7° with no significant impact of fracture pattern (*P* = 0.888). According to the Flynn Scoring Criteria, we observed 81.2% patient to have excellent and remaining 18.8% to have satisfactory outcomes with no poor outcome which was consistent with previously reported outcomes where 80–90% patients had excellent to satisfactory outcomes [5,7,9,13,14,16,21,22]. Furthermore, as the functional outcomes observed in our study were not significantly associated with age, gender, and fracture patterns emphasizes on uniform effectiveness of TENS across all the subgroups withing 6–13 years of age (Table 4).

With a varied post-operative immobilization as reported in literature ranging from 6 weeks of immobilization in a Thomas splint by Ansari *et al.* [13], long knee brace for varied period of 2–5 weeks by Bhuyan and Mohan Singh, Donati *et al.* and others [5,14,21] with our short immobilization period of 2 weeks in above knee brace we found no malalignment or significant LLD in our study group with an excellent to satisfactory outcome in all the patients. However, in contrast to our study, Hathiwalé *et al.*, Pandor *et al.*, and Bairwa *et al.* [7,9,22] observed that though a complete knee range of movement was achieved early, compared to a mean range of 112.7° ± 13.7° at 12 weeks in our study group. They had also observed a higher rate of complication, that is, varus malalignment, LLD, with a comparatively higher rate of poor functional outcome when no post-operative immobilization

was used, emphasizing the superiority of our method of short post-operative immobilization for 2 weeks compared to immediate post-operative mobilization in maintaining alignment and achieving higher functional outcome.

Despite having the strength of being a prospective study where a short immobilization period was given to achieve a good functional and radiological outcome, along with a knee range of movement. Our study is limited by its small sample size, single-center design, short follow-up duration, and lack of a comparative group, which

may limit generalizability of our findings in the population and understanding of long-term effects of remodeling on malalignment. We also noted that due to the short follow-up duration, the common complications such as implant irritation and related infections, refracture after implant removal, and late LLD could not be assessed.

Conclusion

The findings of our study support the use of TENS nail in providing stable fixation, reliable union with an excellent functional outcome, and minimal complications with early mobilization, even with a short immobilization period of 2 weeks. This further strengthens its role as a safe, minimally invasive, and alignment-preserving treatment modality in all the subgroups of 6–13-year age group. However, with all the limitations of the study, we recommend the need of large multicentric randomized comparative study with a longer follow-up duration to validate these findings and to further assess the effect of remodeling potential on limb alignment and patient-related outcome measures of TENS nailing in the 6–13 year age group.

Clinical Message

- TENS provides stable fixation with mechanical axis preservation in children with femur shaft fracture in 6–13 years age group
- Early knee mobilization after a short immobilization period of 2 weeks does not compromise fracture healing and alignment
- Functional outcome assessment using the Flynn criteria demonstrated excellent to satisfactory result in school-aged children when proper techniques were followed
- Complication rates can be minimized with appropriate patient selection, proper techniques of fixation with adherence to fixation principles.

Declaration of patient consent: The authors certify that they have obtained all appropriate patient consent forms. In the form, the patient has given the consent for his/ her images and other clinical information to be reported in the journal. The patient understands that his/ her names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Conflict of interest: Nil **Source of support:** None

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