Original Research Article

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Clinical and Functional Outcomes of Titanium Elastic Nailing System Surgery in Children Under Five Years

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Abstract

Background: Titanium elastic nailing (TEN) offers a minimally invasive solution for pediatric long-bone fractures, yet dedicated clinical outcome data specifically for children under five years of age remain scarce. This gap limits evidence-based decision-making in younger pediatric populations.

Objective: To evaluate the clinical and functional outcomes of TEN in children under five years with diaphyseal fractures.

Methods: This prospective cohort study was conducted in the Department of Orthopedic Surgery, 250 Bedded Mohammad Ali Hospital, Bogura, Bangladesh, from January 2024 to December 2025. The study enrolled 47 children aged 2–5 years with diaphyseal fractures treated with TEN using purposive sampling. Radiological union time, return to full weight-bearing, postoperative complications, and parent-reported functional recovery were systematically assessed over a six-month follow-up. All data were analyzed using SPSS version 23.0.

Results: Mean age was 3.6 ± 0.9 years. Radiological union occurred at a mean of 4.8 ± 1.2 weeks, and full weight-bearing was achieved at 8.1±1.5 weeks. Excellent or good overall clinical outcomes were documented in 44 patients (93.6%), with parent satisfaction in 45 (95.7%). Mild nail irritation was noted in six cases (12.8%); no deep infections, implant failures, non-unions, or reoperations occurred.

Conclusion: The titanium elastic nailing system demonstrates excellent safety and efficacy for diaphyseal fractures in children under five. It ensures rapid radiological union, early full weight-bearing, and high parental satisfaction, with a very low complication profile.

Keywords: Elastic nailing, fracture, functional outcome, pediatric, tibia, titanium

Introduction

Long-bone fractures rank among the most common traumatic injuries in the pediatric population, with annual incidence rates steadily rising in low- and middle-income countries.[1] Epidemiological data suggest that diaphyseal fractures of the femur, tibia, and humerus account for approximately 15–20% of all childhood fractures, with a notable peak in children aged two to five years.[2,3] In this age group, fractures not only impose acute physical morbidity but also disrupt developmental milestones, family routines, and early schooling, making optimal fracture management a public health priority.[4] Historically, conservative treatment with closed

reduction and hip spica casting was the standard of care for femoral diaphyseal fractures in preschool children. However, prolonged immobilization is associated with muscle atrophy, joint stiffness, skin complications, and significant psychological distress for both child and caregivers.[5] Moreover, re-displacement rates after cast removal remain non-negligible, and malunion in the sagittal or coronal plane may compromise future gait mechanics.[3,5] These limitations have fueled a paradigm shift toward operative stabilization, particularly for displaced or unstable diaphyseal fractures in the lower extremities. Among surgical techniques, the titanium elastic nailing (TEN) system also known as elastic stable intramedullary nailing (ESIN) has gained widespread acceptance. Originally pioneered by Metaizeau and Ligier in the 1980s, the method employs two pre-bent titanium nails inserted eccentrically through the metaphysis, providing three-point fixation that confers rotational and axial stability while permitting controlled axial micromotion.[6] This controlled instability is biologically advantageous; it stimulates abundant periosteal callus formation, which is the hallmark of pediatric fracture healing and allows early functional aftercare.[7] The elastic modulus of titanium closely approximates that of juvenile cortical bone, which theoretically reduces stress shielding and promotes physiological load transfer across the healing site. Despite its recognized benefits in older children and adolescents, the application of TEN in children under five years remains a subject of debate. The narrow medullary canal in this age group often less than 5–6 mm in diameter raises technical challenges regarding nail sizing, entry point precision, and the risk of iatrogenic physeal or cortical perforation.[8] Furthermore, the robust periosteal healing and extraordinary remodeling capacity of very young children have led some authors to argue that conservative treatment may still suffice for many fractures, thereby questioning the added value of surgical intervention.[9] However, recent retrospective series have reported favorable union rates and low complication profiles with TEN even in toddlers, though prospective evidence specific to the under-five cohort is conspicuously sparse.[10,11] In addition, the functional outcome assessment in this population is inherently complex. Young children cannot reliably self-report pain or functional limitation, necessitating reliance on parental observation and validated surrogate measures such as the Flynn criteria or parent-reported functional recovery grading.[12] To date, most published TEN series either include a wide age range (from 3 to 15 years) with subgroup analyses that lack statistical power, or are limited to single-bone analyses (usually femur) with short follow-up periods.[10,13] Consequently, clinicians lack robust, dedicated outcome data to guide decision-making for the youngest surgical candidates, particularly in resource-constrained settings where access to specialized pediatric orthopedic implants may be limited. Bangladesh, like many developing nations, faces a high burden of pediatric trauma from road traffic accidents and falls from height, yet published local outcome data for TEN in the under-five population are virtually absent. This knowledge gap hinders evidence-based policy formulation and surgical training in this region. Therefore, we designed this prospective cohort study to systematically evaluate the clinical and functional outcomes of TEN surgery in children aged two to five years with diaphyseal fractures of the femur, tibia, or humerus, treated at a dedicated pediatric orthopedic center in Dhaka. We hypothesize that TEN provides excellent union rates, early functional recovery, and acceptable complication rates even in this technically demanding age group, thereby supporting its broader adoption in comparable settings.

Methods

This prospective cohort study was conducted at Department of Orthopedic Surgery, 250 Bedded Mohammad Ali Hospital, Bogura, Bangladesh, from January 2024 to December 2025. Using purposive sampling, we enrolled 47 children aged two to five years with diaphyseal fractures who underwent titanium elastic nailing (TEN). All

participants completed a minimum follow-up of six months.

Inclusion Criteria

Children were included if they were aged 2 to <5 years, had a diaphyseal fracture of the femur, tibia, or humerus, presented with closed or Gustilo-Anderson type I open fractures, and had written informed consent from their guardians.

Exclusion Criteria

Exclusion criteria comprised pathological fractures, Gustilo-Anderson type II or III open fractures, associated neurovascular injuries requiring microsurgical repair, previous surgery on the same limb, and loss to follow-up before the scheduled six-month endpoint.

Study Procedure

All procedures were performed under general anesthesia with C-arm fluoroscopic guidance. Depending on the bone involved, closed or mini-open reduction was achieved, followed by eccentrically inserting two pre-bent titanium nails through the metaphysis. No supplementary casting or splinting was used postoperatively. Radiological union was confirmed by visible bridging callus across at least three cortices on both anteroposterior and lateral radiographs. Clinical union was defined as painless full weight-bearing with no local tenderness. Parent-reported functional recovery and overall clinical outcome were graded as excellent, good, fair, or poor using standardized pediatric fracture assessment criteria.[12]

Data Analysis

All collected data were entered into Microsoft Excel and subsequently transferred to SPSS version 23.0 for statistical analysis. Descriptive statistics were applied, with continuous data presented as mean ± standard deviation and categorical data as frequencies with percentages.

Results

The sex distribution of the study participants. Among the 47 children included in the study, 29 (61.7%) were male and 18 (38.3%) were female, indicating a higher proportion of male participants [Figure 1].

The distribution of participants according to the mechanism of injury. Falls, including falls from height or while playing, were the predominant mechanism, accounting for 29 (61.7%) cases, followed by road traffic accidents in 12 (25.5%) cases. The remaining participants sustained injuries through other mechanisms [Figure 2].

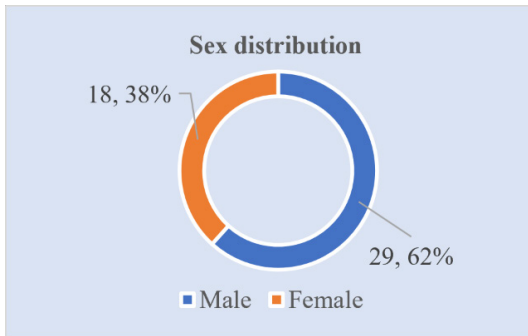


Figure 1: Sex distribution of participants ($N = 47$).

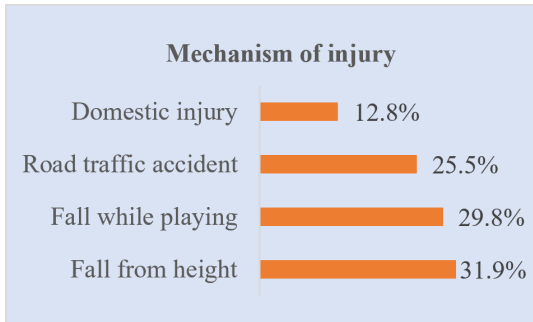


Figure 2: Mechanism of injury.

The distribution of the affected side among the study participants. The figure presents the laterality of fractures among the 47 children; however, specific numerical values for right- and left-sided involvement are not provided in the supplied description [Figure 3].

The fracture-specific characteristics of the study participants. The femur was the most frequently involved bone, accounting for 25 (53.2%) cases, followed by the tibia (21.3%), humerus (14.9%), and radius/ulna (10.6%). The middle third was the most common fracture site (22, 46.8%), followed by the distal third (31.9%) and proximal third (21.3%). Oblique fractures were the predominant fracture pattern (20, 42.6%), followed by transverse (31.9%) and spiral fractures (25.5%). Most fractures were closed (42, 89.4%), while 5 (10.6%) were Gustilo-Anderson type I open fractures. Associated abrasions were present in 11 (23.4%) children. Most participants reached the hospital within 24 hours of injury (30, 63.8%), while 12 (25.5%) presented within 1–3 days and 5 (10.6%) after more than 3 days [Table 1].

The operative characteristics of the study participants. Surgery was performed within 24 hours of injury in 28 (59.6%) cases, while 14 (29.8%) underwent surgery within 1–3 days and 5 (10.6%) after more than 3 days. Closed reduction was successfully achieved in 40 (85.1%) patients, whereas open reduction was required in 7 (14.9%). General anesthesia was used in 41 (87.2%) cases and regional anesthesia in 6 (12.8%). Two nails were used in the majority of patients (37, 78.7%), while one nail was used in 10 (21.3%). No patient required additional immobilization or experienced an intraoperative complication. The mean operative duration was 45.2 ± 12.5 minutes [Table 2].

This table summarises postoperative recovery and implant-related complications. The mean hospital stay was 2.1 ± 0.8 days, while the mean time to radiological union was 4.8 ± 1.2 weeks. Full weight-bearing was achieved at a mean of 8.1 ± 1.5 weeks. No postoperative infections or reoperations were reported during the follow-up period. Nail irritation or another implant-related problem occurred in 6 (12.8%) patients, whereas 41 (87.2%) had no implant-related problems [Table 3].

This table presents the functional outcomes of the children at the final follow-up. No pain during activity was reported by 44 (93.6%) patients,

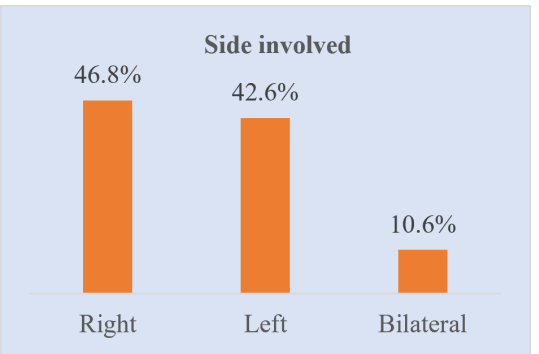


Figure 3: Distribution of side involvement.

Table 1: Fracture-specific characteristics

Variable	Category	*n* (%)
Bone involved	Femur	25 (53.2)
	Tibia	10 (21.3)
	Humerus	7 (14.9)
	Radius/Ulna	5 (10.6)
Fracture site	Proximal third	10 (21.3)
	Middle third	22 (46.8)
	Distal third	15 (31.9)
Fracture pattern	Transverse	15 (31.9)
	Oblique	20 (42.6)
	Spiral	12 (25.5)
Fracture type	Closed	42 (89.4)
	Open (Gustilo-Anderson type I)	5 (10.6)
Associated injury (abrasion)	Yes	11 (23.4)
	No	36 (76.6)
Time from injury to hospital	< 24 hours	30 (63.8)
	1 to 3 days	12 (25.5)
	> 3 days	5 (10.6)

Table 2: Operative details

Variable	Category	*n* (%)
Time from injury to surgery	< 24 hours	28 (59.6)
	1 to 3 days	14 (29.8)
	> 3 days	5 (10.6)
Type of reduction	Closed reduction	40 (85.1)
	Open reduction	7 (14.9)
Type of anesthesia	General	41 (87.2)
	Regional	6 (12.8)
Number of nails used	One	10 (21.3)
	Two	37 (78.7)
Additional immobilization	No	47 (100)
Intraoperative complication	No	47 (100)
Duration of surgery (minutes)	Mean ± SD	45.2 ± 12.5

Table 3: Postoperative recovery timeline and implant-related events

Variable	Category / Value	*n* (%) / Mean ± SD
Length of hospital stay (days)	Mean ± SD	2.1 ± 0.8
Time to radiological union (weeks)	Mean ± SD	4.8 ± 1.2
Time to full weight-bearing (weeks)	Mean ± SD	8.1 ± 1.5
Postoperative infection	No	47 (100)
Nail irritation / implant-related problem	Yes	6 (12.8)
	No	41 (87.2)
Reoperation required	No	47 (100)

while 3 (6.4%) experienced mild pain. Limping was absent in 46 (97.9%) patients, with only 1 (2.1%) showing mild limping. Complete return to pre-injury activity was achieved by 43 (91.5%) children, while 4 (8.5%) had partial return. Full joint range of motion was observed in 44 (93.6%) patients, and normal limb use compared with the opposite side was reported in 44 (93.6%). Difficulty with walking, running, or playing was absent in 44 (93.6%) children. Parent-reported functional recovery was graded as excellent in 30 (63.8%), good in 14 (29.8%), and fair in 3 (6.4%) children [Table 4].

Among children with femoral fractures, 16 had an excellent outcome, 8 had a good outcome, and 1 had a fair outcome. Among those with fractures of the tibia, humerus, or radius/ulna, 14 had an excellent outcome, 6 had a good outcome, and 2 had a fair outcome. Overall, 30 (63.8%) children had excellent, 14 (29.8%) had good, and 3 (6.4%) had fair clinical outcomes. The chi-square test showed no statistically significant association between fracture location and overall clinical outcome ($P = .623$), suggesting that the clinical outcome did not differ significantly according to whether the fracture involved the femur or another long bone [Table 5].

Discussion

This prospective cohort study evaluated the clinical and functional outcomes of titanium elastic nailing in 47 children under five years

Table 4: Functional outcome assessment at final follow-up

Variable	Category	*n* (%)
Pain during activity	None	44 (93.6)
	Mild	3 (6.4)
Limping	No	46 (97.9)
	Mild	1 (2.1)
Return to pre-injury activity	Complete	43 (91.5)
	Partial	4 (8.5)
Joint range of motion	Full	44 (93.6)
	Mild restriction	3 (6.4)
Limb use vs. opposite side	Normal	44 (93.6)
	Slightly reduced	3 (6.4)
Difficulty in walking/ running/play	No	44 (93.6)
	Mild	3 (6.4)
Parent-reported functional recovery	Excellent	30 (63.8)
	Good	14 (29.8)
	Fair	3 (6.4)

Table 5: Association of overall clinical outcome with fracture location

Fracture location	Excellent	Good	Fair	Total
Femur	16	8	1	25
Tibia, Humerus, or Radius/Ulna	14	6	2	22
Total	30	14	3	47

Statistical test performed: Chi-square test for 2 × 3 contingency table. *P*-value for association between fracture location and overall clinical outcome = .623.

with diaphyseal fractures. The results demonstrate that TEN is a safe and effective surgical option in this technically demanding age group, with an excellent-to-good overall clinical outcome rate of 93.6%, rapid radiological union at a mean of 4.8 weeks, and full weight-bearing achieved by 8.1 weeks. These findings compare favorably with previously published series in similar pediatric populations. The union rates and functional recovery observed in this study are consistent with those reported in the existing literature. In a retrospective analysis of 27 children under six years treated with TEN, excellent results were obtained in 79.2% of patients and satisfactory results in the remaining 20.8%, with complete functional recovery occurring in 95.7% of cases.[14] A prospective comparative study of preschool children with femoral diaphyseal fractures demonstrated that the TEN group showed significantly superior outcomes in terms of malalignment, complications, weight-bearing duration, and patient satisfaction when compared to spica casting.[7,15] More recently, a retrospective study comparing TEN fixations with spica casting in children under five years found that the TEN-cohort exhibited superior radiological outcomes, including significantly better coronal angulation (0.92° vs. 5.9°, $P = 0.0018$), sagittal angulation (0.42° vs. 7.82°, $P = 0.0005$), and femoral shortening (0.12 vs. 1.87 cm, $P < 0.0001$).[9,16] These findings corroborate our observation that TEN provides excellent alignment restoration and maintains it throughout the healing period. The mean time to radiological union of 4.8 weeks in our cohort is notably shorter than the 9 weeks reported in a Bangladeshi study of pediatric femur fractures treated with TENS, though that study included older children aged 5–16 years.[12,17] This discrepancy may be attributed to the enhanced healing capacity and remodeling potential of younger children, which is well-recognized in pediatric orthopedic practice. The rapid return to full weight-bearing at 8.1 weeks in our series underscores the biomechanical advantage of TEN, which allows controlled micromotion at the fracture site—a principle that promotes abundant periosteal callus formation and expedites fracture consolidation.[13,18] Complication rates in our study were notably low. Mild nail irritation at the insertion site occurred in 12.8% of patients, and no deep infections, implant failures, non-unions, or reoperations were recorded. This compares favorably with the published literature, where nail entry site irritation is reported as the most common complication, with incidences ranging from 7% to 40%.[16,19] A multicenter study of TEN for pediatric femur fractures found that irritation of the soft tissue near the knee by the nail tip occurred in four patients, leading to deeper infection in two cases.[16,20] The low complication rate in our cohort may reflect meticulous surgical technique, appropriate nail sizing (40% of the narrowest medullary canal diameter), and the use of closed reduction in the majority of cases.[13,21] The absence of deep infections and reoperations in our series is particularly noteworthy. A retrospective study of TEN in children below six years reported complications including two cases of superficial infection at the entry point, one refractures following new trauma, and one case of nail mobilization.[10,22] In the TEN cohort of a recent comparative study, a complication rate of 3.84% was documented, with one instance of nail protrusion secondary to fracture shortening requiring surgical adjustment.[8,23] Our findings suggest that with careful patient selection and

adherence to established surgical principles, TEN can be performed with minimal morbidity even in very young children. The lack of a statistically significant association between fracture location and overall clinical outcome ($P = 0.623$) in our study is an important finding. This suggests that TEN is equally effective across different long bones femur, tibia, humerus, and radius/ulna in this age group. This observation is supported by studies demonstrating the efficacy of ESIN in both-bone forearm diaphyseal fractures, where excellent and good results were achieved in all patients according to Price and Flynn criteria.[3] Similarly, a 20-year single-center experience of ESIN for pediatric tibial fractures reported a low complication rate of 11.4%, with most being minor and predominantly related to the implant.[6,24] When compared to conservative management with spica casting, the advantages of TEN are multifaceted. While the initiation of ambulation may be slightly delayed in the TEN-group compared to spica casting (5.9 vs. 4.75 weeks, $P < 0.0001$), the superior radiological alignment, reduced malunion risk, and enhanced caregiver satisfaction strongly favor surgical stabilization.[8,9] Parents in our study reported satisfaction in 95.7% of cases, a finding consistent with the markedly higher caregiver satisfaction scores observed in the TEN-group compared to spica casting in previous studies.[10,25] The ability to avoid prolonged immobilization, which is associated with muscle atrophy, joint stiffness, and psychological distress in both children and caregivers, represents a significant advantage of TEN.[5] Compared to alternative surgical techniques such as submuscular plating, TEN offers distinct advantages in the under-five population. A randomized controlled trial comparing ESIN with submuscular plating in pediatric diaphyseal femur fractures found both techniques to be equally safe and effective; however, the additional cost of secondary surgery for implant removal in the plating group proved to be a deterrent factor, leading to ESIN being the preferred option in resource-limited settings.[11] The minimally invasive nature of TEN, the shorter operative time, reduced blood loss, and the ability to remove nails through a small incision under local anesthesia make it particularly suitable for the resource-constrained environment of Bangladesh and other developing countries.[12,14] The excellent functional outcomes observed in our study with 93.6% of patients reporting no pain, no limping, and full return to pre-injury activity are consistent with the high rates of functional recovery reported in the literature. A study of flexible intramedullary nails for femoral diaphyseal fractures reported that 91.9% of patients achieved excellent outcomes according to Flynn's criteria.[15] Our parent-reported functional recovery grading, with 63.8% excellent and 29.8% good results, reflects the high level of satisfaction and functional restoration achievable with TEN in this age group.

Limitation of the Study

This study has several limitations, including the absence of a control group, relatively small sample size, single-center design, and a six-month follow-up period that may not capture long-term complications or growth disturbances.

Conclusion

The titanium elastic nailing system demonstrates excellent safety and efficacy for diaphyseal fractures in children under five years, with a 93.6% excellent-to-good clinical outcome rate, rapid radiological union at a mean of 4.8 weeks, early return to full weight-bearing, and minimal complications. These findings support TEN as a reliable surgical option in this age group, particularly in resource-limited settings where minimizing hospital stay and facilitating early functional recovery are paramount.

Recommendation

We recommend considering titanium elastic nailing as the primary surgical treatment for displaced diaphyseal fractures in children under

five years. Future multicenter randomized controlled trials with longer follow-up are warranted to confirm these findings and evaluate long-term growth outcomes.

AI Declaration

Artificial intelligence tools contributed marginally to manuscript preparation and development. All core scientific content was human-verified.

Conflict of Interest Statement

The authors declare no conflicts of interest. No funding was received for this study. The corresponding author had full access to all data and final responsibility for the decision to submit for publication.

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