Nepal Orthopedic Association Journal
https://doi.org/10.59173/noaj.20251102b

ORIGINAL ARTICLE

Titanium Elastic Nailing System in Treatment of Fracture Shaft of Tibia in Children and Adolescents: A Prospective Observational Study

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ABSTRACT

BACKGROUND
Tibial shaft fractures are common pediatric injuries, often requiring surgical intervention when conservative management fails. The Titanium Elastic Nailing System (TENS) has gained popularity due to its minimally invasive nature, stable fixation, and ability to preserve growth plates. This study evaluates the functional and radiological outcomes of pediatric tibial shaft fractures treated with TENS in a resource-limited setting.

METHODS
A prospective observational study was conducted at the National Level Tertiary Care Trauma Center in Nepal, from February 2019 to January 2020. Forty-six patients aged 5–18 years with unstable tibial shaft fractures were treated with TENS. Functional outcomes were assessed using Flynn's criteria, and radiological union was evaluated using the Radiographic Union Scale for Tibia (RUST). Statistical analysis was performed to identify factors influencing outcomes.

RESULTS
The mean age of participants was 9.89 ± 2.79 years, with 58.7% male. Most fractures were closed (93.5%) and located in the middle third of the tibia (69.6%). Excellent outcomes were achieved in 84.8% of cases, with a mean union time of 10.35 ± 2.25 weeks. Significant predictors of poor outcomes included limb length discrepancy ($p = 0.007$), angulation ($p < 0.001$), delayed union ($p < 0.001$), restricted knee range of motion ($p = 0.019$), and persistent pain ($p = 0.001$).

CONCLUSION
TENS is an effective treatment for pediatric tibial shaft fractures, offering excellent functional and radiological outcomes. Proper alignment, timely union, and early mobilization are critical for optimal recovery. Addressing complications such as angulation and persistent pain, particularly in resource-limited settings, is essential to maximize outcomes.

KEYWORDS
Titanium Elastic Nailing System (TENS), pediatric tibial fractures, Flynn's criteria, radiological union, limb length discrepancy

INTRODUCTION

Tibial and fibular fractures are among the most common pediatric long bone injuries, accounting for approximately 15% of such fractures, second only to radial/ulnar and femoral fractures.[1] These fractures are also the second most common cause of pediatric admissions following trauma. The majority of tibial shaft fractures in children can be effectively managed with closed reduction and casting. However, operative intervention is necessary when reduction cannot be achieved or maintained, such as in cases of mal-rotation, angulation, excessive overriding, involvement of the proximal or distal third of the tibial shaft, severe soft tissue injury, or open fractures.[2] Certain fracture patterns, such as those with more than 10 degrees of valgus deformity with an intact fibula, may not be adequately controlled with casting alone.[3]

Various operative treatment options for pediatric tibial fractures include external fixation, transfixion pins in casts, plate-screw fixation, and more recently, elastic intramedullary nailing systems such as Enders or titanium nails.[4] Among these, the Titanium Elastic Nailing System (TENS) has gained popularity due to its minimally invasive nature, stable fixation, and ability to allow early mobilization. TENS operates on a three-point fixation principle, with two elastic nails symmetrically bracing the inner bone at three points, providing essential flexural, axial, translational, and rotational stability for optimal fracture healing.

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Studies have shown that TENS results in improved functional outcomes, fewer complications, and higher patient satisfaction, with faster recovery and a quicker return to normal activities. Its ability to provide stable fixation without violating the growth plate, preserve the periosteum, and reduce infection risks makes it particularly beneficial for pediatric patients. Additionally, titanium nails are more elastic than stainless steel, limiting permanent deformation and minimizing stress shielding, further promoting healing.[5-10] However, despite its advantages, TENS has its complications. The most common issues include skin irritation at the nail entry site, nail migration, and, in rare cases, malunion or nonunion. These complications are generally minor and can be managed effectively with appropriate surgical technique and postoperative care.[11]

This study aims to evaluate the functional and radiological outcomes of pediatric tibial shaft fractures treated with TENS.

METHODS

This prospective, hospital-based observational study was conducted at the Department of Orthopedics and Trauma Surgery, National Level Tertiary Care Trauma Center in Nepal, over a one-year period from February 2019 to January 2020.

The study included 46 pediatric patients aged 5 to 18 years with unstable closed or open tibial shaft fractures classified as Gustilo type I to IIIA. Patients with mid-shaft fractures or fractures at the junction of the upper or lower-middle third, as well as those with failed closed reduction or loss of reduction after casting, were included, while those with metaphyseal or pathological fractures were excluded. The surgical technique involved closed reduction and internal fixation using Titanium Elastic Nails (TENS), with preoperative planning based on Flynn's formula for nail diameter selection (Figure 1).

Postoperatively, patients with comminuted fractures were immobilized using a posterior slab or a patellar tendon-bearing (PTB) cast. Follow-up evaluations were conducted at 2 weeks, 6 weeks, 12 weeks, 18 weeks, and 6 months' post-surgery and data entry of final follow at 6 months was done, assessing functional outcomes using Flynn's criteria and radiological union via the Radiographic Union Scale for Tibia (RUST), range of motion(ROM) of ankle and knee were assessed. Any reduction in ROM compared to the contralateral normal ankle and knee was recorded as a restriction in ROM. Statistical analysis was performed using SPSS v22.0, applying descriptive statistics such as mean, standard deviation, and frequency distributions to analyze key variables, including demographics, fracture characteristics, surgical duration, complications, angulation, limb length discrepancy, and

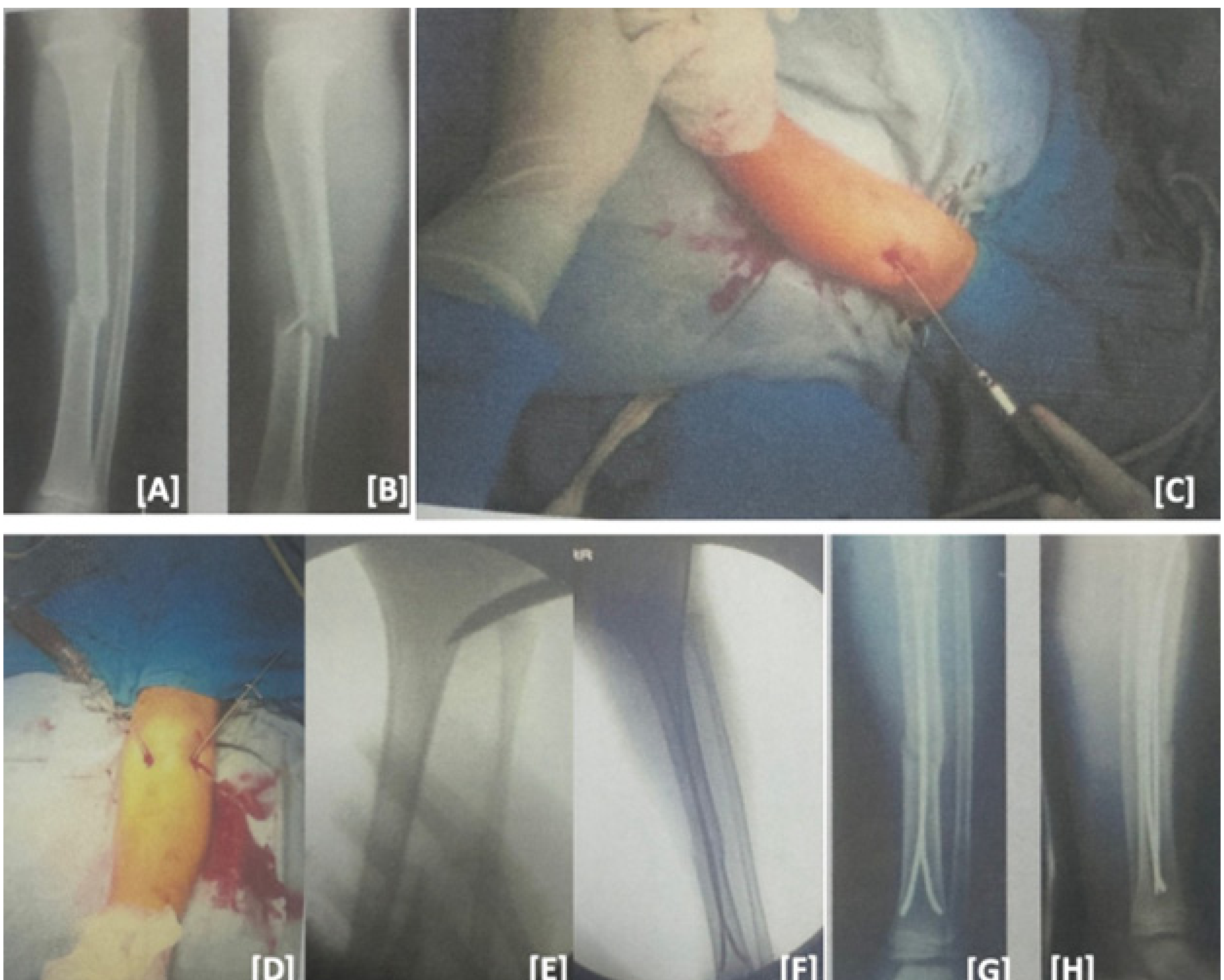

Figure 1: A,B: Preoperative Radiograph of Skeletally immature Pediatric Tibia in Anteroposterior(AP) and Lateral view showing tibial Shaft fracture; C,D: Intraoperative Images Showing Points of TENS nail Insertion in Proximal tibia after Prebending the nail; E,F: Fluroscopy imaging showing the adequate positioning of entry awl avoiding the physis and insertion of TENS nail; G,H: Postoperative Radiograph in AP and Lateral view showing adequate reduction of fracture with 3 point fixation of TENS nail

time to union. Ethical approval was obtained from the institutional ethical committee, and informed consent was secured from all participants or their guardians prior to study enrollment.

RESULTS

The study included 46 patients with a mean age of 9.89 ± 2.79 years, of whom 58.7% were male. Right-sided fractures were more common (63.0%), and the majority were closed fractures (93.5%). The primary mode of injury was falls (65.2%), followed by road traffic accidents (32.6%). Most fractures occurred at the middle third of the tibia (69.6%) with oblique fractures being the most common pattern (54.3%). Fibular fractures were present in 23.9% of cases. General anesthesia was used in 78.3% of patients (Table 1).

Table 1: General characteristics of the participants (Categorical Variables)

Variable	Subgroup/Category	Frequency (%)
Gender	Male	27 (58.7%)
	Female	19 (41.3%)
Side	Left	17 (37.0%)
	Right	29 (63.0%)
Type	Closed	43 (93.5%)
	Open	3 (6.5%)
Mode of Injury	Fall	30 (65.2%)
	RTA	15 (32.6%)
	Sports Injury	1 (2.2%)
Level of Fracture	Distal 3rd	10 (21.7%)
	Middle 3rd	32 (69.6%)
	Proximal 3rd	4 (8.7%)
Pattern of Fracture	Spiral	14 (30.4%)
	Oblique	25 (54.3%)
	Transverse	5 (10.9%)
	Comminuted	2 (4.3%)
Fibula Fracture	Absent	35 (76.1%)
	Present	11 (23.9%)
Anesthesia	GA	36 (78.3%)
	Spinal	10 (21.7%)
ROM Knee	Full	44 (95.7%)
	Restriction in ROM	2 (4.3%)
ROM Ankle	Full	43 (93.5%)
	Restriction in ROM	3 (6.5%)
Pain at 6 Months	Absent	44 (95.7%)
	Present (Diffuse)	2 (4.3%)

Functional Outcomes:

At the final follow-up, 95.7% had full knee range of motion, and 93.5% had full ankle range of motion. Postoperative pain was absent in 95.7% of cases. Based on Flynn's criteria, 84.8% had excellent outcomes, while 15.2% had fair results.

The mean interval from injury to surgery was 2.67 ± 1.59 days, with a mean surgical duration of 49.07 ± 6.91 minutes. Hospital stay averaged 2.87 ± 1.18 days. Partial weight-bearing was initiated at 6.63 ± 0.93 weeks, with an average limb length discrepancy of 2.13 ± 2.52 mm at 6 months. The mean angulation at 6 months was 2.07 ± 2.46 degrees, and the mean time for radiological union was 10.35 ± 2.25 weeks (Table 2).

Table 2: General characteristics of the participants (Continuous Variables)

Variable	Mean ± SD (Median)
Age (years)	9.89 ± 2.79 (10.0)
Interval injury-surgery (days)	2.67 ± 1.59 (2.0)
Duration of surgery (min)	49.07 ± 6.91 (47.0)
Hospital stay (days)	2.87 ± 1.18 (3.0)
Partial weight bearing (weeks)	6.63 ± 0.93 (6.0)
LLD at 6 months (mm)	2.13 ± 2.52 (2.0)
Angulation at 6 months	2.07 ± 2.46 (2.0)
Time for union (weeks)	10.35 ± 2.25 (10.0)

Patients with full knee ROM had a significantly higher rate of excellent outcomes ($p = 0.019$), whereas those with mild restrictions were more likely to have fair results. Similarly, the presence of persistent, diffuse pain at six months was strongly associated with poorer outcomes ($p = 0.001$), with all cases experiencing pain classified as fair. Other variables, including gender, fracture side, fracture type (closed vs. open), mode of injury (fall, RTA, sports injury), fracture level (proximal, middle, distal third), fracture pattern (spiral, oblique, transverse, comminuted), fibular fracture, and type of anesthesia (general vs. spinal), did not show statistically significant associations with the final outcome ($p > 0.05$) (Table 3).

The analysis identified limb length discrepancy (LLD) at six months ($p = 0.007$), angulation at six months ($p < 0.001$), and time to union ($p < 0.001$) as significant factors influencing functional outcomes in pediatric tibial shaft fractures treated with Titanium Elastic Nailing System (TENS). On the other hand, age ($p = 0.050$), interval between injury and surgery ($p = 0.745$), duration of surgery ($p = 0.979$), hospital stay ($p = 0.711$), and time to partial weight-bearing ($p = 0.291$) were not significantly associated with final outcomes (Table 4).

Table 3: Factor affecting the outcome using Flynn criteria for TENS

Variable	**Category**	**Excellent (n=39)**	**Fair (n=7)**	**Chi-Square**	**p-value**
Gender	Male	23 (50.0%)	4 (8.7%)	0.008	0.928
	Female	16 (34.8%)	3 (6.5%)		
Side	Left	16 (34.8%)	1 (2.2%)	1.821	0.177
	Right	23 (50.0%)	6 (13.0%)		
Type	Closed	37 (80.4%)	6 (13.0%)	0.816	0.366
	Open	2 (4.3%)	1 (2.2%)		
Mode of Injury	Fall	25 (54.3%)	5 (10.9%)	0.270	0.874
	RTA	13 (28.3%)	2 (4.3%)		
	Sports Injury	1 (2.2%)	0 (0.0%)		
Level of Fracture	Distal 3rd	9 (19.6%)	1 (2.2%)	0.512	0.774
	Middle 3rd	27 (58.7%)	5 (10.9%)		
	Proximal 3rd	3 (6.5%)	1 (2.2%)		
Pattern of Fracture	Spiral	12 (26.1%)	2 (4.3%)	0.469	0.926
	Oblique	21 (45.7%)	4 (8.7%)		
	Transverse	4 (8.7%)	1 (2.2%)		
	Comminuted	2 (4.3%)	0 (0.0%)		
Fibula Fracture	Absent	30 (65.2%)	5 (10.9%)	0.098	0.754
	Present	9 (19.6%)	2 (4.3%)		
Anesthesia	GA	30 (65.2%)	6 (13.0%)	0.270	0.604
	Spinal	9 (19.6%)	1 (2.2%)		
ROM KNEE	Full	38 (82.6%)	5 (10.9%)	7.876	0.019
	Mild Restrictions	1 (2.2%)	1 (2.2%)		
ROM ANKLE	Full	35 (76.1%)	7 (15.2%)	0.786	0.675
	Mild Restrictions	3 (6.5%)	0 (0.0%)		
Pain at 6 Months	Absent	39 (84.8%)	5 (10.9%)	11.649	0.001
	Present (Diffuse)	0 (0.0%)	2 (4.3%)		

Table 4: Factor affecting the outcome using Flynn criteria for TENS

Variable	**df**	**p-value**	**95% Confidence Interval (Lower – Upper)**
AGE (years)	44	0.050	-0.003 – 4.465
Interval between injury and surgery (days)	44	0.745	-1.547 – 1.115
Duration of surgery (min)	44	0.979	-5.704 – 5.858
Stay in hospital (days)	44	0.711	-0.807 – 1.173
Partial weight bearing (weeks)	44	0.291	-0.360 – 1.173
LLD at 6th months (mm)	44	0.007	-4.649 – -0.772
Angulation at 6 months	44	<0.001	-5.896 – -2.712
Time for union (weeks)	44	<0.001	-4.894 – -1.700

DISCUSSION

The present study evaluated the functional and radiological outcomes of pediatric tibial shaft fractures managed with the Titanium Elastic Nailing System (TENS). Overall, the majority of patients achieved excellent outcomes (84.8% as per Flynn's criteria), with a mean radiological union time of approximately 10.35 weeks. These findings are in line with previous literature, which has consistently highlighted the benefits of TENS—namely, its minimally invasive nature, preservation of the growth plate, and facilitation of early mobilization.[12]

The analysis of factors affecting outcomes based on Flynn's criteria for the Titanium Elastic Nailing System (TENS) revealed that knee range of motion (ROM) and the presence of pain at six months were significant predictors of functional outcomes. Patients with full knee ROM had a significantly higher rate of excellent outcomes ($p = 0.019$), whereas those with some restrictions were more likely to have fair results. Clinically, full knee ROM after TENS indicates optimal fracture healing, proper implant positioning, and effective rehabilitation, leading to excellent functional outcomes.[13] ROM restrictions may result from residual stiffness, scar tissue formation, or inadequate physiotherapy, contributing to fair results. Pain at six months' post-surgery could signify complications such as implant irritation, delayed union, or soft tissue inflammation, which may hinder recovery and limit ROM. Additionally, insufficient post-operative rehabilitation or poor patient compliance with exercises can exacerbate these issues. Addressing these clinical factors through meticulous surgical technique, early mobilization, and structured rehabilitation programs is essential to optimize outcomes and minimize pain and stiffness.[14]

Similarly, persistent, diffuse pain at six months post-TENS surgery strongly correlated with fair outcomes ($p = 0.001$), often due to complications like delayed union, non-union, or implant irritation.[15] In Nepal, limited access to rehabilitation and physiotherapy exacerbates pain, hindering recovery. Cultural and economic barriers may delay further medical intervention, prolonging discomfort and impairing functionality. Persistent pain discourages physical therapy, restricting ROM and delaying recovery.[16] Addressing these issues requires multidisciplinary care, including close post-operative monitoring, timely complication management, and improved access to rehabilitation. Enhancing patient education on follow-up and therapy adherence is also critical to reduce pain and optimize functional outcomes in resource-limited settings.[17]

The analysis identified limb length discrepancy (LLD) at six months as a significant factor affecting outcomes ($p = 0.007$). Clinically, LLD may result from improper fracture reduction, delayed union, or growth disturbances in pediatric patients.[18n] Even minor discrepancies can alter gait mechanics, leading to compensatory changes in posture and joint loading, which may cause secondary pain or functional limitations.[19] In resource-limited settings like Nepal, where manual labor and uneven terrain are common, LLD can significantly impact a patient's ability to perform daily activities and maintain livelihoods.[20]
The analysis revealed that angulation at six months post-TENS surgery was a highly significant predictor of outcomes ($p < 0.001$). Clinically, angulation may result from inadequate fracture reduction, unstable fixation, or premature weight-bearing.[21] Even minor angulations can lead to malalignment, affecting joint mechanics, gait, and overall limb function.[22] In settings like Nepal, where physical demands are high due to rugged terrain and manual labor, angulation can severely impair a patient's ability to perform daily activities and work.

Time to union significantly influenced functional outcomes in pediatric tibial shaft fractures treated with TENS ($p < 0.001$). Delayed union, caused by factors like inadequate stability, infection, or poor healing, prolongs recovery and immobilization, hindering early return to activity.[23] Prolonged immobilizations may also lead to stiffness, muscle atrophy, or joint contractures, further compromising outcomes. Optimal surgical technique, proper post-operative care, and addressing risk factors like nutrition and infection are crucial for timely union. Regular follow-up and patient education on rehabilitation adherence are essential to optimize recovery and functional outcomes.[24]

The findings highlight the importance of achieving proper fracture alignment, minimizing limb length discrepancies, and ensuring timely union to optimize recovery. While TENS offers significant advantages, including minimal invasiveness and preservation of the growth plate, attention must be paid to potential complications such as angulation, delayed union, and implant-related issues. In resource-limited settings like Nepal, addressing barriers to post-operative care and rehabilitation is critical to maximizing patient outcomes. Overall, TENS represents a reliable and effective treatment option for pediatric tibial fractures, aligning with the growing demand for timely recovery and return to functional activity in young patients.

Future studies involving larger cohorts and extended follow-up periods are recommended to further validate these findings and refine treatment protocols. However, several limitations should be acknowledged. The sample size of 46 patients, though sufficient for an observational study, remains relatively small, and the six-month follow-up period may not adequately capture long-term complications such as growth disturbances or late-onset deformities. Also there was a possible selection bias, and there was no comparison group. Furthermore, the single-center design of this study may limit the generalizability of the results to broader populations. Addressing these limitations in future research will enhance the robustness and applicability of the findings.

CONCLUSION

In summary, the Titanium Elastic Nailing System offers a reliable and effective option for the management of pediatric tibial shaft fractures. Its ability to provide stable fixation, maintain alignment, and promote early mobilization results in excellent functional and radiological outcomes. Future research with larger sample sizes, multicenter collaboration, and longer follow-up periods would be valuable to further validate these findings and to compare TENS with alternative surgical modalities.

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