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Original Article
Titanium elastic nail system in compound tibial fractures in children and adolescents

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Abstract: *Background:* Closed reduction and casting remain the gold standard treatment for tibial shaft fractures in children and adolescents. However, surgical intervention is indicated in cases of unstable fractures, open fractures, polytrauma, compartment syndrome, and fractures with severe soft tissue injury. The present study aimed to evaluate the safety and efficacy of Titanium Elastic Nailing System (TENS) in the management of compound tibial shaft fractures in children and adolescents. *Methods:* This retrospective study reviewed 18 cases of tibial shaft fractures treated with TENS from 2018 to 2021. Clinical outcomes were assessed based on fracture alignment, delayed union, non-union, infection, range of motion (ROM) of the knee and ankle, limb length discrepancy, and time to fracture union during follow-up visits. Outcomes were classified according to Flynn's criteria. *Results:* All patients achieved fracture union at a mean duration of 11.6 weeks, with full weight-bearing permitted at an average of 10 weeks. Limb shortening was observed in 4 patients. There were no cases of delayed union or non-union. At the final follow-up, 10 patients demonstrated excellent outcomes, while 8 had satisfactory outcomes. The most common complication was infection at the fracture site, observed in 6 patients. *Conclusion:* TENS is a safe, reliable, and effective treatment modality for compound tibial shaft fractures in children and adolescents. It facilitates rapid fracture healing with an acceptable complication rate.

Keywords: Tibial shaft fracture, TENS, ESIN, children and adolescents, paediatric

Introduction

With a reported incidence of 15%, tibial fractures are among the most common long bone fractures in the paediatric population [1]. Closed reduction and casting remain the cornerstone of management; however, surgical intervention is warranted in cases involving neurovascular injury, polytrauma, open fractures, and unstable fractures that result in unacceptable angulation, malrotation, or shortening [2]. Various surgical techniques have been described for managing these fractures, including cross K-wire fixation, external fixators, intramedullary (IM) nailing, and plating with screws [3, 4]. In fractures with significant soft tissue loss, external fixators are generally preferred; however, they are associated with complications such as malunion, delayed union, limb length discrepancy (LLD), and pin site infections [2]. IM nailing may not be feasible in children and young adolescents due to the risk of injury to the proximal tibial physeal plate and the narrow diameter of the medullary canal [2, 5]. Historically, external fixators were the primary treatment for unstable tibial fractures but were linked to complications such as infection, overgrowth, and refracture [5].

The titanium elastic nailing system (TENS) has gained popularity for the fixation of long bone fractures in skeletally immature patients due to its ease of use and lower complication rates [1]. TENS has demonstrated high union rates and is widely utilized in paediatric femoral shaft fractures [6, 7]. The advantages of using the Titanium Elastic Nailing System (TENS) in long bone fractures include closed reduction, short hospitalization duration, low infection and refracture rates, early return to function, preservation of the fracture hematoma, and a physeal-sparing entry point [3]. Additional benefits include early fracture union facilitated by micromotion at the fracture site, early weight-bearing,

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minimal scarring, and high patient and parent satisfaction. The excellent biocompatibility and elasticity of titanium further enhance the utility of TENS. Notably, the elasticity promotes callus formation by reducing stress shielding, thereby enabling faster union and early weight-bearing. The ideal implant for managing paediatric tibial fractures should act as a simple, load-sharing internal splint that maintains alignment and length while allowing early mobilization until bridging callus forms. It must also preserve the blood supply to the epiphysis. TENS fulfils these criteria, making it an optimal choice for paediatric tibial fractures. Although several studies have reported satisfactory outcomes with TENS in closed tibial fractures [6, 8], there is limited literature addressing its use in paediatric and adolescent populations with high-energy open tibial fractures. However, concerns have been raised regarding its decreased rigidity, which may hinder bone healing, and significant complication rates in older children. Furthermore, it remains unclear whether TENS usage in open tibial fractures is associated with a higher risk of deep infection and delayed fracture healing. This study aimed to share our experience using TENS for managing compound tibial fractures in paediatric and young adolescent populations. Specifically, we sought to evaluate its safety and effectiveness in terms of bone healing and the incidence of wound complications with immediate flexible nailing.

Material and methods

Study population

A retrospective study was conducted at our center between May 2018 and April 2021 to evaluate TENS fixation in children and adolescents with compound tibial fractures. Informed consent was obtained from the parents of all enrolled patients. Institutional ethical committee approval was secured, and the study adhered to the ethical standards of the 1964 Declaration of Helsinki, as revised in 2000. Patients were identified through a thorough review of hospital records within the specified timeframe.

Inclusion & exclusion criteria

Inclusion criteria: 1) Grade 1, 2, and 3A open tibial fractures, as classified by the Gustilo-Anderson (GA) system; 2) Polytrauma patients; 3) Floating knee injuries.

Exclusion criteria: 1) Patients <5 years and >14 years of age; 2) Follow-up duration <6 months; 3) Pathological fractures; 4) Incomplete patient records; 5) Closed fractures and grade 3B open injuries, as per the GA classification; 6) Fractures with infected wounds; 7) Fractures with severe comminution and massive bone loss; 8) Fractures treated conservatively with acceptable alignment; 9) Patients who underwent procedures other than TENS.

Data retrieval and analysis of parameters

For all patients, full-leg anteroposterior (AP) and lateral radiographs were obtained. Each X-ray was reviewed to ensure the inclusion criteria were met. Demographic and baseline data, including age at injury, sex, weight, affected side, mechanism of injury, associated injuries, neurovascular impairment, time from injury to antibiotic administration, and time from injury to surgery, were collected from patient case records (**Figure 1**). Open fracture wounds were categorized using the Gustilo-Anderson (GA) classification system [17], while fractures were classified based on the AO/OTA classification system. Intraoperative and immediate postoperative data, including the need for fasciotomies, type of wound closure (primary vs. secondary), duration of postoperative antibiotics, and occurrence of compartment syndrome, were recorded. Immediate postoperative X-rays were used to assess coronal and sagittal angulation. Routine clinical and radiological follow-ups were conducted to evaluate knee and ankle range of motion (ROM), final coronal and sagittal angulation, time to union, and postoperative complications such as malunion, delayed union, non-union, limb length discrepancy (LLD), growth arrest, and infection. The percentage of patients requiring implant removal was also recorded. Fracture union was defined as the presence of bridging callus in at least three of the four cortices on AP and lateral radiographs. Functional outcomes were assessed using Flynn's criteria [18]. Complications and the need for secondary procedures, excluding nail removal, were also documented.

Surgical technique

All patients underwent surgery under spinal anaesthesia. The compound fracture site was thoroughly debrided and irrigated with normal

Figure 1. A 8 year/male patient presented 6 hours after injury with open wound (grade 2) to his left leg on medial side (A), X-ray showed spiral fracture both bone left leg at the junction of proximal 2/3rd and distal 1/3rd (B), immediate post-operative X-ray after wound debridement and CRIF with TENS along-with above knee back slab (C), superficial necrosis of wound over lateral aspect 2 days after surgery (D), sutures from lateral side were removed and daily cleaning and dressing was done (E), 2 months follow-up X-ray showed union (F), functional outcome at 2 months follow-up (G-J), note the complete healing of the wound on medial aspect of distal leg (black arrow) (L, lateral, M, medial).

saline. The appropriate nail size was determined using Flynn's formula: nail diameter = 0.4 × narrowest diameter of the medullary canal. Each nail was manually contoured into a "C" shape, positioning the tip on the concave side of the bowed nail to achieve the principle of three-point fixation. The entire length of the nail was pre-contoured so that the apex of the bow rested at the fracture site, which optimizes resistance to mal-aligning forces. Both nails were contoured symmetrically to ensure balanced effects, with a bend radius approximately three times the diameter of the medullary canal. A 2-3 cm incision was made on the medial and lateral aspects of the proximal tibia, 1.5-2 cm distal to the physis. Using a handheld awl, an entry point was created perpendicular to the bone surface and then gradually angulated to 45° relative to the shaft axis. The pre-contoured nails were inserted into the medullary canal medially and laterally, starting with the side where the fracture fragment was overlapped to facilitate better reduction. Both nails were manually advanced to the fracture site. Following closed reduction, one TENS nail was carefully passed beyond the fracture site, and its position was confirmed under fluoroscopy (C-arm) in both anteroposterior and lateral views. Once correctly positioned within the medullary canal, the nail was advanced distally, stopping proximal to the distal tibial physis. The second nail was then inserted and negotiated across the fracture site in a similar manner. Proximally, the nails were cut, leaving approximately 1 cm exposed outside the cortex. To prevent skin irritation, the ends of the nails were left straight rather than bent. The skin was palpated to ensure the nail tips were not excessively prominent, and any entrapped soft tissue was released. The compound fracture site was then closed. Equal-diameter TENS nails were used to prevent differential loading on the opposing cortex and to ensure maximum bending and corrective forces at the fracture site. Postoperatively, an above-knee posterior slab was applied to the operated limb.

Post-operative assessment and follow-up

The above-knee back slab was removed 3 weeks after surgery, and patients were allowed to begin partial weight-bearing ambulation. Postoperatively, patients were assessed at 3, 6, 9, 12, and 18 months to monitor for complications, including infection, non-union, delayed union, time to fracture union, range of motion (ROM) in the knee and ankle, and limb length discrepancy (LLD). Radiographic alignment was assessed using a goniometer to measure deformities in the coronal and sagittal planes. For coronal angulation, mid-diaphyseal lines were drawn on X-ray images of the proximal and distal segments of the tibia, and the angle between these lines represented the deformity in the coronal plane. For sagittal angulation, full-length lateral X-rays of the tibia were obtained, and the mechanical axes of the proximal and distal segments were drawn. The angle subtended between these axes represented the deformity in the sagittal plane. Limb length discrepancy (LLD) was assessed using a measuring tape with the patient in a supine position. The length from the anterior superior iliac spine (ASIS) to the medial malleolus was measured and compared bilaterally. Knee and ankle ROM were evaluated by measuring passive flexion and extension angles using a goniometer. Clinico-radiological criteria were used to identify delayed union and non-union. Fracture union was defined clinically as the absence of pain at the fracture site and radiologically by the presence of bridging callus on at least three cortices.

Statistical analysis

Descriptive statistics were utilised for each of demographics, co-morbidities and outcomes. Continuous variables were described using mean and standard deviation (SD), where appropriate. Categorical variables were described using frequencies, percentages and range. All analysis were undertaken using SPSS version 26 (IBM Corp. 2019).

Results

The study included 14 male and 4 female patients, with a mean age of 9.83 years (range: 7-13 years) (**Table 1**). The mean hospital stay was 4.9 days (range: 2-8 days), with longer stays observed in patients with open fractures requiring daily dressing changes, intravenous antibiotics, and repeat debridement. All acute fractures were treated using TENS. The most commonly utilized nail diameters were 2 mm, 2.5 mm, and 3 mm, respectively. The mean duration between injury and surgery was 1.1 days (range: 0-3 days). Eight patients had left-

Table 1. Demographic Characteristics of the patients

Pt.	Gender	Age	Side	Fracture Characteristics	Fracture type	MOI.	Associated fracture	Pt. Wt.	Hospitalstay	In jury to surgery duration (days)	Nailremoval (wk)
1	M	12	R	grade 1	A2	RTA	none	30	3	0	26
2	F	10	R	grade 2	A1.	FFH	fibula	22	3	2	30
3	M	8	R	grade 1	A3	RTA	none	35	2	1	0
4	M	7	L	grade 1	A3	RTA	fibula	20	3	0	30
5	M	10	R	grade 2	A1	RTA	fibula	28	3	3	25
6	F	13	L	grade 2	A1	FFH	none	24	5	3	0
7	M	12	R	grade 2	A2	FFH	none	32	6	2	28
8	M	11	R	grade 2	A2	RTA	femur (I/L)	26	3	1	32
9	M.	11	L	grade 1	A1	RTA	fibula	23	2	1	27
10	M	9	L	grade 1	A3	FFH	fibula	26	2	2	0
11	M	10	L	grade 3A	B2	FFH	femur (C/L)	28	10	0	24
12	M	8	R	grade 3A	A3	FFH	clavicle (I/L)	33	8	1	35
13	F	8	R	grade 2	A1	RTA	fibula	36	7	0	22
14	M	11	R	grade 2	A2	RTA	fibula	19	7	1	24
15	M	12	L	grade 2	A2	FFH	none	25	5	0	0
16	F	10	R	grade 2	A1	RTA	none	34	6	1	21
17	M	8	L	grade 2	A1	FFH	none	38	6	0	23
18	M	7	L	grade 3A	A3	FFH	humerus (I/L)	21	8	2	0

Pt. - patient, M - male, F - female, R - right, L - left, RTA - road traffic accident, FFH - fall from height, SI - sports injury, MOI - mechanism of injury, wk - week.

sided injuries, while ten had right-sided injuries. According to the Gustilo-Anderson classification, 5 patients had grade 1 open fractures, 10 had grade 2, and 3 had grade 3A. Automobile accidents and falls from height were equally common mechanisms of injury, each accounting for 50% of cases. Fractures involved the middle one-third of the tibia in 15 patients and the distal one-third in 3 patients. Based on the AO/OTA classification, 17 fractures were type A, and 1 was type B. Concomitant fractures were observed in 11 patients (61.1%), including fractures of the ipsilateral humerus, ipsilateral femur, contralateral femur, ipsilateral clavicle (one case each), and the ipsilateral fibula (seven cases). The mean weight of patients was 27.7 kg (range: 19-38 kg). The mean follow-up period was 23.9 months (**Table 2**). All fractures achieved union at a mean of 11.6 weeks (range: 6-16 weeks). The mean time to achieve full weight-bearing was 10 weeks (range: 6-14 weeks). There were no cases of delayed union, malunion, or non-union in the study. Out of 18 patients, 13 underwent nail extraction surgery, with an average time to removal of 26.6 weeks. Five patients did not return for nail removal. The mean time to administer the first dose of antibiotics after injury was 4.6 hours (**Table 3**). Antibiotics were administered for more than 48 hours in 11 patients and less than 48 hours in 7 patients (grade I: 5 patients, grade II: 2 patients). No patients in the study developed compartment syndrome or required fasciotomy.

Complications

The most common complication observed was infection at the compounding site, affecting 6 patients (33.3%) (**Table 2**). Of these, 5 patients developed superficial infections, which were successfully managed with daily dressing and oral antibiotics. One patient with a grade 3A compound fracture developed a deep infection, necessitating repeat debridement and intravenous antibiotics. Two patients experienced superficial infections at the nail entry site, while 4 out of the 5 patients with superficial infections developed superficial wound necrosis at the compounding site. These cases were effectively managed with daily dressing and oral antibiotics. Primary wound closure of the compounding site was achieved in all patients except one with a grade 3A fracture, who required repeat debridement and secondary wound closure. Three patients reported irritation at the nail entry site. At the final follow-up, no patients exhibited angulation greater than 10° in either the coronal or sagittal planes. The mean fracture site angulation was 3.4° on anteroposterior views and 4.9° on lateral views. Four patients had limb length discrepancies (LLD) of less than 2 cm, but no cases of limb overgrowth were observed. Notably, the complication rate was higher in patients with more severe open fractures compared to those with lower-grade injuries.

Functional outcome

Functional outcomes were assessed using Flynn's criteria, which revealed 10 excellent and 8 satisfactory results. No patients had a poor outcome in this series. The satisfactory results were primarily attributed to wound infections, irritation at the nail entry site, and limb length discrepancies.

Discussion

Closed manipulation and cast immobilization remain the gold standard treatment for pediatric tibial fractures [3]. However, long-term immobilization and frequent follow-up visits are essential for successful conservative management, which can be particularly challenging in our clinical setting. Surgical intervention is indicated for patients with unstable fractures, secondary loss of reduction, open fractures, neurovascular injury, or polytrauma. Titanium elastic nails (TENS) have emerged as an important fixation technique for stabilizing long bone fractures in children [19]. The advantages of TENS include minimal soft tissue damage, a reduced risk of infection and refracture, early mobilization, and a quicker return to normal activities [9]. While good results with TENS have been reported for forearm and femur fractures, its outcomes for tibial fractures are not as well established. A load-sharing device like TENS is an ideal choice for treating paediatric tibial fractures because it helps maintain alignment, promotes early mobilization, and preserves the growth plates. TENS not only facilitates alignment and rotational correction during treatment but also enhances callus formation and accelerates union through controlled micromotion at the fracture site. Additionally, the minimally invasive nature of TENS reduces the risk

Table 2. Radiological and Clinical outcome of the patients

Pt	Fracture	Follow-up (months)	Union time (weeks)	Residual Deformity (0) (C/S)	Complication	wt. Bearing. (weeks)	Pintractinf/irri.	LLD (s/l)	Flynncriteria
1	grade 1	10	8	0/0	N	6	N	N	E
2	grade 2	16	11	0/2	N	8	irritation	N	S
3	grade 1	22	10	7/0	N	8	N	0.5 cm (short)	E
4	grade 1	22	6	-4/1	N	10	N	N	E
5	grade 2	16	10	6/8	superficial infection	6	N	N	S
6	grade 2	20	10	8/0	N	12	N	N	E
7	grade 2	24	12	0/6	superficial infection	14	infection	N	S
8	grade 2	26	14	0/0	N	6	N	N	E
9	grade 1	28	8	0/0	N	10	irritation	N	S
10	grade 1	15	12	3/1	N	10	irritation	N	S
11	grade 3A	9	16	4/3	Deep infection	12	N	1 cm (short)	S
12	grade 3A	13	18	9/6	N	16	N	N	E
13	grade 2	33	12	3/2	N	12	N	1 cm (short)	S
14	grade 2	40	15	0/0	superficial infection	10	N	N	E
15	grade 2	30	16	2/2	N	12	N	N	E
16	grade 2	20	10	-2/3	superficial infection	6	N	N	E
17	grade 2	14	6	6/3	N	8	N	N	E
18	grade 3A	38	16	0/4	superficial infection	14	infection	1.5 cm (short)	S

N - none, C/S - coronal/sagittal, "-" - valgus, inf/irri - infection/irritation, s/l - shortening/lengthening, E - excellent, S - satisfactory.

Table 3. Antibiotic and operating room data

Patient	Fracture	Time to first dose of antibiotics (hours)	Duration of antibiotics >48 hours
1	grade 1	4	no
2	grade 2	6	yes
3	grade 1	8	no
4	grade 1	2	no
5	grade 2	1	yes
6	grade 2	2.5	no
7	grade 2	3	yes
8	grade 2	5	yes
9	grade 1	10	no
10	grade 1	8	yes
11	grade 3A	6	yes
12	grade 3A	4	yes
13	grade 2	8	yes
14	grade 2	5	yes
15	grade 2	2	no
16	grade 2	1	no
17	grade 2	3	yes
18	grade 3A	4.5	yes

of surgical site infections, as it requires small incisions. However, elastic nailing of tibial fractures presents unique challenges due to the triangular shape of the tibia and its eccentric surrounding musculature [10].

The purpose of our study was to evaluate whether immediate flexible nailing (TENS) can be effectively used for open tibial fractures in children and adolescents without causing wound or bone healing complications. Patients with open tibial fractures are more likely to experience high-energy trauma, with a significantly higher incidence of polytrauma (71% in open fractures versus 25% in closed fractures). Our study findings indicate that the prompt application of TENS for tibial fractures results in a very low risk of wound complications. The early fracture union observed in our study can be attributed to the timely administration of antibiotics and meticulous soft tissue handling, which contribute to a quicker return to daily activities and early mobilization. This may explain the superior functional outcomes observed in our cohort. Initially, intramedullary fixation using TENS was limited to closed fractures; however, it has since been recognized as beneficial for open fractures as well. Basaran et al. [13] applied TENS to open tibial fractures and reported excellent and good results in 45% and 55% of cases, respectively. Similarly, Uludag et al. [12] used TENS in 35% of their patients with open tibial fractures, with all cases achieving union and 43% and 57% of patients experiencing excellent and satisfactory outcomes, respectively. In our study, 55.5% of patients had grade 2 open fractures, 27.7% had grade 1 fractures, and 16.6% had grade 3A fractures. All patients in our series achieved union, with 33.3% and 22.2% of patients demonstrating excellent and satisfactory outcomes, respectively.

Grade 3 fractures (according to the Gustilo-Anderson classification) are frequently treated with external fixation. Meyers et al. [20] reported a 66% complication rate in their patients treated with external fixators. Similarly, Kubiak et al. [6] compared external fixation to TENS in 31 patients with tibial fractures and found a 50% complication rate, including 2 cases of delayed union, 3 non-unions, and 2 malunions. In contrast, our study found no cases of non-union, malunion, or delayed union. Only one patient with a grade 3A injury developed a deep infection, which was managed with repeat debridement and secondary wound closure. This excellent healing rate may be due to TENS imparting minimal damage to the surrounding soft tissues and not introducing infectious risk from pin tract sites. Many authors have noted that open fractures tend to take longer to heal than closed fractures [12]. Brien et al. [11] reported an average time to union of 15 weeks for open tibial fractures. In our study, the average time to union was 11.6 weeks, suggesting that open fractures, although more prone to complications, can still heal effectively with TENS. However, careful monitoring is necessary as these fractures are more susceptible to delayed union. Age-related differences in the time to union may also be important, particularly in older patients. Gordon et al. [14] found that patients with a mean age of 11.7 years had normal union times, whereas patients aged 14.1 years experienced delayed union. In our study, the average time to union was 11.8 weeks for patients older than 10 years and 11.5 weeks for those under 10 years old. Thus, we suggest that older children receiving TENS treatment should be closely monitored for the possibility of delayed union. The natural flexibility of TENS, which allows for angulation at the fracture site during union, may increase the risk of malunion, although this was not observed in our study. Brian et al. [11] reported angulation of >5° in two patients, while Sankar et al. [5] noted angulation between 5° and 10° in two patients - one in the coronal plane and the other in the sagittal plane. In our series, none of the patients had angulation >10°, though eight patients had angulation between 5° and 10°. This may be attributed to the shorter follow-up in our study, as well as the inclusion of older patients (>10 years), who have reduced remodelling potential. The mean follow-up was 23.9 months for patients with angulation <5°, while it was 18.1 months for those with angulation between 5° and 10°. Infection rates for open tibial fractures have been reported to range from 3.6% to 15%. Skaggs et al. [21], in a review of 554 fractures, found a 3% infection rate in patients operated on within 6 hours of injury and a 2% infection rate for those treated within 7 hours. In our study, all patients received intravenous antibiotics upon presentation in the emergency room, as did the cohort in Skaggs et al.'s study. This suggests that immediate antibiotic administration is more crucial than the timing of surgery itself. Furthermore, all patients in our study had primary wound closure without the need for grafts or flap cover. This may be due to minimal soft tissue damage and meticulous management, which allowed effective primary closure without tension. Irritation and infection at the nail entry site are common side effects reported in studies using TENS. Mani et al. [15] reported superficial pin site infections in 4.4% of patients and pin tract irritation in 13.3%. In our study, three patients experienced irritation at the nail entry site, but no additional nail removal procedures were required. Two patients developed superficial infections at the pin sites, which were managed effectively with oral antibiotics and daily dressing changes.

Limb length discrepancy (LLD) is another common complication after tibial fractures in children. Walamastha et al. [16] reported that 3.6% of patients had LLD of less than 15 mm. In our study, four patients had a mean shortening of 10 mm, but none of them experienced symptoms related to the discrepancy. There are a few limitations in our study. First, it was a single-center study with retrospectively collected data. Second, the sample size was small, and there was no control group for comparison with other treatment modalities. To draw more definitive conclusions, future research should focus on conducting prospective, multicenter studies with larger sample sizes.

Conclusion

The Titanium Elastic Nailing System (TENS) is a simple, reliable, and effective method for treating compound tibial fractures in paediatric and adolescent patients. When combined with prompt antibiotic administration upon arrival in the emergency room, continued post-operative antibiotics, and careful soft tissue management during initial wound closure, TENS offers significant advantages. These include reduced blood loss, shorter surgical time, and decreased hospital stays, while still ensuring timely fracture healing. Additionally, TENS allows for early initiation of physiotherapy, promoting faster rehabilitation. While potential complications may arise, careful intraoperative precautions can mitigate most risks, making TENS a preferred treatment option for paediatric tibial fractures.

Disclosure of conflict of interest

None.

Abbreviations

TENS, Titanium elastic nailing system; ROM, Range of motion; LLD, Limb length discrepancy; GA, Gustilo Anderson.

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