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Research Article

Clinical Outcomes of Titanium Elastic Nailing System versus Dynamic Compression Plating in Adolescent Femoral Shaft Fractures: A Retrospective Cohort Study

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ABSTRACT

Introduction: The optimal surgical management of adolescent femoral shaft fractures remains controversial because Titanium Elastic Nailing System (TENS) and Dynamic Compression Plating (DCP) differ in biomechanics, indications, and complication profiles.

Aim: To compare fracture union, functional outcomes, and complications following TENS and DCP fixation in adolescent femoral shaft fractures.

Materials and Methods: A retrospective cohort study was conducted at two tertiary care teaching hospitals involving adolescents aged 11–18 years with closed femoral shaft fractures treated with TENS or DCP between March 2023 and March 2026. Clinical, radiological, and functional outcomes were evaluated using Flynn's criteria.

Results: Eighty-one patients (48 TENS, 33 DCP) with a mean age of 14.8 years were analyzed. Union was achieved in all patients. Mean union time was 12 weeks with TENS and 13.1 weeks with DCP. TENS enabled earlier toe-touch weight bearing (5 vs. 7.85 weeks) but showed higher rates of entry-site irritation (22.9%), loss of reduction (10.4%), and malunion (18.7%). DCP demonstrated superior stability in comminuted and length-unstable fractures but had a higher incidence of superficial infection (12.1% vs. 4.1%).

Conclusion: Both TENS and DCP achieved excellent fracture union. TENS is preferred for younger adolescents with length-stable fractures owing to faster rehabilitation, whereas DCP offers superior stability for older adolescents and length-unstable fractures. Implant selection should be individualized based on patient age and fracture morphology.

Keywords: Titanium elastic nailing system, dynamic compression plating, adolescent femoral shaft fracture, femoral shaft fracture, fracture fixation, flynn criteria.

INTRODUCTION

NEED FOR THE STUDY

Diaphyseal fractures of the femur represent one of the most frequent major orthopaedic injuries in the pediatric demographic, standing as a leading cause of prolonged hospitalization and substantial socio-economic burden.[1,2] The epidemiologic distribution of these injuries exhibits a bimodal pattern, with a pronounced second peak occurring during adolescence secondary to high-energy mechanisms such as athletic trauma and motor vehicle collisions.[3,2] Adolescence constitutes a unique physiological and biomechanical transitional phase in which the patient presents with a narrowing medullary canal, rapidly increasing body mass, and a diminishing potential for spontaneous skeletal remodelling.[4,5] The surgical management algorithm in this specific cohort remains an area of active clinical equipoise. While preschool children are definitively managed with spica casting and near-skeletally mature patients undergo rigid interlocking intramedullary nailing, the application of rigid antegrade nails in younger adolescents is severely constrained by the devastating risk of iatrogenic avascular necrosis of the femoral head-particularly with piriformis fossa entry-and premature greater trochanteric epiphysiodesis leading to coxa valga.[6,7] Consequently, orthopaedic surgeons must continuously navigate between flexible intramedullary options, primarily the Titanium Elastic Nailing System (TENS) and extramedullary constructs such as the Dynamic Compression Plate (DCP) to achieve optimal stabilization.[8,4]

TENS and DCP utilize fundamentally divergent biomechanical principles to secure fracture union. TENS serves as a biological, load-sharing internal splint based on symmetrical three-point intramedullary fixation.[3,9] This flexible construct deliberately permits controlled micromotion at the fracture site, accelerating secondary osteogenesis through the formation of abundant external bridging callus while meticulously preserving the fracture hematoma and periosteal vascularity.[2,10] Clinically, TENS is highly advantageous due to its minimally invasive insertion, translating to significantly reduced operative durations, negligible intraoperative hemorrhage, and rapid early mobilization.[11,12] However, the mechanical limits of flexible titanium implants are frequently exceeded in the adolescent population. Current evidence-based guidelines generally restrict the use of TENS to patients weighing less than 50 kilograms and presenting with length-stable fracture morphologies, such as transverse or short oblique patterns.[6,5,9] Utilizing TENS in heavier adolescents or in the presence of comminuted, long oblique, and length-unstable fractures precipitates a markedly elevated risk of construct failure. Such failure frequently manifests as loss of reduction, acute shortening, varus collapse, and permanent limb length discrepancies.[4,13,14] Furthermore, hardware prominence at the insertion site frequently causes severe soft-tissue irritation and bursitis, occasionally necessitating premature implant extraction.[3,13]

Conversely, plate osteosynthesis bypasses robust callus formation by neutralizing interfragmentary strain and delivering absolute mechanical rigidity, thereby steering the physiological response toward primary osteonal healing.[5,10] Plating effectively neutralizes the deforming muscular forces of the adolescent thigh, ensuring reliable anatomic restoration and rotational stability even in highly comminuted or length-unstable fractures, and safely accommodating patients exceeding the 50-kilogram threshold.[4,15] Despite these mechanical superiorities, traditional open plating necessitates extensive lateral dissection and periosteal stripping, which disrupts the local vascular envelope.[8,13] Comparative literature indicates that plate fixation is associated with significantly longer surgical times, increased intraoperative blood loss, and a heightened vulnerability to both superficial and deep surgical site infections.[8,12] Additionally, subsequent hardware extraction is a highly invasive reconstructive procedure that leaves residual cortical stress risers, exposing the adolescent to the risk of postoperative refracture.[15,1]

Despite an expanding body of comparative literature, profound gaps persist regarding the absolute superiority of TENS versus DCP specifically within the adolescent demographic. Recent systematic reviews and meta-analyses explicitly highlight substantial methodological flaws in the existing evidence base, noting high observational bias, variable outcome definitions, and insufficient sample sizes, ultimately yielding low-quality evidence that precludes definitive standardization.[1,12] Furthermore, the vast majority of current trials aggregate data across a broad pediatric age spectrum (e.g., 5 to 12 years), which inadvertently masks the specific biomechanical demands and complication profiles unique to older, heavier adolescents.[8,1] While several randomized controlled trials advocate for elastic nailing as the gold standard due to reduced perioperative morbidity,[12] other cohort studies document unacceptably high rates of malunion and hardware failure when TENS is applied to heavier patients, concluding that plate fixation is clinically superior in this transitional age group.[4,13]

Given these conflicting data and the distinct complication profiles inherent to each implant, a direct, highly controlled comparison between TENS and DCP strictly within the adolescent population is clinically imperative. Elucidating the precise radiological, functional, and perioperative outcomes of these two divergent fixation strategies will address a critical void in current pediatric trauma literature. Establishing rigorous, evidence-based parameters for this specific demographic will refine implant selection criteria, standardize surgical decisionmaking, and optimize long-term patient outcomes while minimizing perioperative complications. These unresolved controversies form the foundational rationale for the present investigation.

METHODS

Following approval from the Institutional Ethics Committee, a retrospective cohort study was conducted at Nandi Medical College and Research Institute, Chikkaballapur. The study included all adolescents aged 11-18 years who underwent surgical treatment for femoral shaft fractures using either Titanium Elastic Nailing System (TENS) or Dynamic Compression Plating (DCP) between March 2023 and March 2026. Follow-up data for patients who subsequently received continued clinical care at other tertiary teaching hospitals, including Hassan Institute of Medical Sciences, were incorporated into the analysis using available clinical records and radiographic documentation. Statistical analysis of the collected data was performed using SPSS version 16.0.

Hospital case records, operative notes, and corresponding radiographs were reviewed retrospectively. Relevant demographic, clinical, radiological, operative, and follow-up details were extracted systematically from the available records for subsequent analysis.

INCLUSION CRITERIA

Patients were eligible for inclusion if they met all of the following criteria:

- Age between 11 and 18 years.
- Simple diaphyseal fracture of the femoral shaft.
- Presence of an open distal femoral physis.
- Minimum postoperative follow-up of 12 months.

EXCLUSION CRITERIA

Patients were excluded if they had:

- Age below 11 years or above 18 years.
- Complete physeal closure.
- Less than 12 months of follow-up.
- Open (compound) fractures of the femoral shaft.

Preoperative anteroposterior and lateral radiographs of the femur were reviewed to document fracture morphology. Fractures were classified according to their pattern (transverse, oblique, spiral, or comminuted) and anatomical location within the shaft (proximal third, middle third, or distal third).

The choice of fixation method was determined by the operating surgeon after considering fracture location, fracture configuration, patient age, and body weight. Based on these factors, patients underwent either TENS fixation or DCP fixation.

For patients managed with TENS, titanium elastic nails of appropriate diameter were inserted using the standard AO-recommended technique through an antegrade approach appropriate to the fracture location.

Patients treated with DCP underwent fixation through the conventional lateral approach to the femur. After provisional reduction with Kirschner wires, fixation was achieved using either a **3.5-mm or 4.5-mm Dynamic Compression Plate**, ensuring placement of at least four cortices of screw purchase on either side of the fracture.

Routine postoperative wound dressing was performed on the **2nd, 5th, and 10th postoperative days**, followed by suture removal according to wound healing.

Rehabilitation was initiated early. Isometric quadriceps strengthening exercises together with hip and knee range-of-motion exercises were encouraged from the immediate postoperative period.

Patients were reviewed at regular intervals. Follow-up visits were scheduled monthly during the first six months, every three months during the following year, and every six months thereafter for an additional one and a half years.

Fracture healing and functional outcomes were assessed using the **Flynn *et al.* scoring system** after radiological union had been achieved. Based on the predefined criteria, the final outcome was categorized as **excellent, successful, or poor**.

Table No. 1: Flynn *et al.* Scoring Criteria

Parameter	Excellent	Successful	Poor
Limb length discrepancy	<1 cm	<2 cm	>2 cm
Angular deformity	<5°	<10°	>10°
Pain	Absent	Absent	Present
Complications	None	Mild	Major

RESULTS

A total of **81 adolescents** with femoral shaft fractures were included in the study. Of these, **54 were males** and **27 were females**. Based on the method of fixation, **48 patients** who underwent Titanium Elastic Nailing System (TENS) were categorized as **Group A**, whereas **33 patients** treated with Dynamic Compression Plating (DCP) constituted **Group B** (Table 2).

The overall mean age of the study population was **14.8 years**. In Group A, the majority of patients (**40/48**) belonged to the **11-14-year** age group, while **8 patients** were aged **15-18 years**. In contrast, Group B predominantly consisted of older adolescents, with **26 patients** between **15 and 18 years** and **7 patients** between **11 and 14 years** (Table 3).

Table No. 2: Distribution of patients according to treatment modality

Group	Number of patients
Group A (TENS)	48
Group B (DCP)	33

Table No. 3: Age-wise distribution of patients

Age group	Group A	Group B
11-14 years	40	7
15-18 years	8	26

Road traffic accidents (RTA) represented the most frequent mechanism of injury, accounting for **67 cases (82.7%)**. Sports-related injuries were responsible for **13 cases (16.0%)**, while **one patient (1.2%)** sustained injury due to other causes (Table 4).

Table No. 4: Distribution according to mode of injury

Mode of injury	Number of patients
Road traffic accident	67
Sports-related injury	13
Others	1

Regarding fracture location, the **middle third of the femoral shaft** was the most commonly affected region, representing **67.9%** of all fractures. Fractures involving the proximal and distal thirds accounted for **19.7%** and **12.3%**, respectively.

The pattern of fracture distribution differed between the two treatment groups. In Group A, fractures were predominantly located in the middle third (**83.3%**), whereas proximal and distal third fractures constituted **12.5%** and **4.1%**, respectively. In Group B, middle-third fractures accounted for **45.5%**, proximal-third fractures **30.3%**, and distal-third fractures **24.4%** (Table 5).

Table No. 5: Distribution according to fracture site

Fracture site	Group A	Group B
Middle third	40	15
Proximal third	6	10
Distal third	2	8

Fracture morphology also varied between the groups. In the TENS group, **transverse fractures** were the most common configuration (**56.25%**), followed by oblique (**22.9%**), spiral (**12.5%**), and comminuted fractures (**6.25%**). Conversely, the DCP group demonstrated a predominance of **comminuted fractures (45.4%)**, followed by transverse (**27.3%**), oblique (**15.15%**), and spiral fractures (**15.15%**) (Table 6).

Table No. 6: Distribution according to fracture pattern

Fracture type	Group A (%)	Group B (%)
Transverse	27 (56.25)	9 (27.3)
Oblique	11 (22.9)	5 (15.15)
Spiral	6 (12.5)	5 (15.15)
Comminuted	3 (6.25)	15 (45.4)

Radiological union was achieved in **all patients**, resulting in an overall union rate of **100%**. The mean time to fracture union was **12 weeks** in the TENS group and **13.1 weeks** in the DCP group. Patients treated with TENS were able to begin toe-touch weight bearing earlier, with a mean duration of **5 weeks**, compared with **7.85 weeks** in the DCP group (Table 7).

Table No. 7: Time to fracture healing

Outcome	Group A (weeks)	Group B (weeks)
Mean time to union	12	13.1
Mean time to toe-touch weight bearing	5	7.85

Complications assessed during follow-up included loss of reduction, malunion, limb-length discrepancy, irritation at the nail entry site, superficial infection, implant removal, and implant failure.

Irritation at the nail entry site was observed exclusively in the TENS group, affecting **11 of 48 patients (22.9%)**. All symptomatic patients underwent early implant removal, after which complete symptom resolution was achieved.

Malunion occurred in **9 patients (18.7%)** in Group A and in **one patient (3%)** in Group B. All cases demonstrated an angular deformity of **less than 5°**, with **varus malalignment** being the most frequently encountered deformity.

Loss of reduction was identified only in the TENS group, occurring in **5 patients (10.4%)**. These included **one oblique**, **two spiral**, and **two comminuted fractures**, all of which required revision surgery. No patient in the DCP group experienced loss of reduction.

Limb-length discrepancy was noted in **five patients (10.4%)** treated with TENS. Among these, **four patients developed shortening (8.3%)**, while **one patient demonstrated lengthening (2.1%)**. In the DCP group, **one patient (3%)** developed limb shortening, and no cases of lengthening were observed.

Superficial wound infection occurred more frequently following DCP fixation. It was observed in **4 patients (12.1%)** in Group B compared with **2 patients (4.1%)** in Group A. All affected patients responded to intravenous antibiotics administered according to culture and sensitivity reports.

Implant removal was performed in **24 patients (50%)** in the TENS group and **19 patients (57.6%)** in the DCP group. Implant failure occurred in **3 patients (6.25%)** treated with TENS and in **one patient (3%)** managed with DCP (Table 8).

Table No. 8: Distribution of complications

Complication	Group A (TENS) n (%)	Group B (DCP) n (%)
Loss of reduction	5 (10.4)	0
Malunion	9 (18.7)	1 (3.0)
Limb-length discrepancy	5 (10.4)	2 (6.0)*
• Lengthening	1 (2.1)	0
• Shortening	4 (8.3)	1 (3.0)
Entry-site irritation	11 (22.9)	0
Superficial infection	2 (4.1)	4 (12.1)
Implant removal	24 (50.0)	19 (57.6)
Implant failure	3 (6.25)	1 (3.0)

DISCUSSION

The primary objective of this retrospective study was to evaluate the clinical, radiological, and functional outcomes of the Titanium Elastic Nailing System (TENS) versus Dynamic Compression Plating (DCP) in the management of closed femoral shaft fractures in adolescents. Our findings validate that while both modalities predictably achieve complete fracture union, their clinical indications, healing dynamics, and complication profiles diverge significantly based on implant biomechanics and fracture morphology.

The demographic distribution in our cohort demonstrated a strong male preponderance and a mean age of 14.8 years, with road traffic accidents (82.7%) and sports injuries (16.0%) accounting for nearly all fractures. This aligns directly with epidemiological literature characterizing adolescent diaphyseal femur fractures as predominantly high-energy trauma injuries.[16,17]

Treatment allocation in our study revealed a clear age-wise and morphological preference. TENS was overwhelmingly favoured in younger adolescents (11-14 years) presenting with length-stable transverse fractures located in the middle third of the diaphysis. Conversely, DCP was predominantly utilized in older adolescents (15-18 years) with length-unstable, comminuted patterns, frequently extending into the proximal or distal thirds. This treatment divergence reflects established biomechanical principles. TENS functions as a biological, load-sharing internal splint that relies on symmetrical three-point intramedullary fixation, making it highly effective for length-stable midshaft fractures in lighter patients.[18] In contrast, DCP acts as a rigid, load-bearing construct that neutralizes interfragmentary strain, which is mechanically requisite for heavily comminuted or metaphyseal fractures where flexible nails cannot secure adequate cortical purchase.[18,8]

Both techniques yielded a 100% union rate, confirming their fundamental efficacy. However, the physiological pathways to union differed. The mean time to complete radiographic union was slightly faster in the TENS cohort (12 weeks) compared to the DCP cohort (13.1 weeks), and TENS patients initiated toe-touch weight bearing significantly earlier (5 weeks versus 7.85 weeks). Because TENS insertion is minimally invasive, it meticulously preserves the fracture hematoma and periosteal vascularity. The inherent elasticity of the titanium implants permits controlled physiological micromotion, which accelerates secondary osteogenesis through robust external bridging callus formation.[18] Open plating disrupts the local soft-tissue envelope and achieves absolute mechanical rigidity, thereby bypassing callus formation and steering the bone toward primary osteonal healing, a process that is biologically slower.[18] It should be noted that our union timeline for TENS differs slightly from some previous comparative cohorts, such as Jolly *et al.*, who reported faster union times with plates (10.7 weeks) compared to TENS (14.3 weeks).[8] The expedited healing observed in our TENS cohort is likely attributable to strict patient selection, reserving elastic nails exclusively for younger adolescents with stable fracture patterns highly conducive to secondary healing.

The complication profiles encountered strictly reflect the biomechanical limits of each implant. In the TENS group, 10.4% of patients experienced a loss of reduction requiring reoperation, exclusively within length-unstable variants (oblique, spiral, and comminuted). Furthermore, the TENS cohort exhibited an 18.7% incidence of minor malunion (predominantly varus <5°) and a 10.4% rate of limb-length discrepancy (both shortening and lengthening). These findings strongly corroborate the warnings of Sink *et al.* and Moroz *et al.*, who demonstrated that applying flexible intramedullary nails to length-unstable fractures or to heavier, older adolescents precipitates a markedly elevated risk of construct deformation, acute shortening, and varus collapse.[19,20] For the older adolescents and comminuted fractures in our cohort, DCP proved mechanically superior, effectively preventing loss of reduction (0%) and minimizing malunion (3%) by actively neutralizing the severe deforming muscular forces of the mature thigh.

Conversely, soft-tissue complications were highly implant-specific. Entry-site irritation was the most frequent complication overall, affecting 22.9% of the TENS cohort. This is a well-documented phenomenon caused by the prominence of the nail tips at the distal femoral metaphysis, which frequently leads to local bursitis but reliably resolves following routine implant removal.[21,22] Despite this localized irritation, avoiding extensive surgical exposure with TENS significantly mitigated deep tissue complications. The DCP cohort demonstrated a markedly higher incidence of superficial surgical site infections (12.1% versus 4.1% in TENS). This elevated infectious morbidity is a direct consequence of the extensive lateral dissection, muscle-splitting, and periosteal stripping necessary for plate application, a finding heavily supported by recent meta-analyses highlighting the soft-tissue risks of open plating.[1]

Implant failure occurred in a small minority of patients (TENS 6.25%, DCP 3%), reflecting the extreme mechanical demands placed on pediatric implants during early rehabilitation. Elective implant removal was frequently performed in both cohorts (50% in TENS, 57.6% in DCP). While extraction of prominent titanium nails is a rapid, minimally invasive outpatient procedure, removal of a dynamic compression plate represents a highly invasive secondary surgery that risks postoperative refracture through residual cortical stress risers.[18,8]

In summary, neither TENS nor DCP is universally superior for adolescent femoral shaft fractures; their success is strictly contingent upon evidence-based patient selection. TENS represents an exceptional, biologically advantageous option for younger adolescents (11-14 years) with length-stable diaphyseal fractures, facilitating rapid secondary healing, early weight-bearing, and minimal infectious morbidity. However, its mechanical limitations preclude its use in older adolescents and comminuted fractures. In these challenging clinical scenarios, DCP remains the essential standard, trading the advantages of a minimally invasive approach for the absolute mechanical rigidity required to reliably prevent malunion and maintain anatomical alignment.

CONCLUSION

Both the Titanium Elastic Nailing System (TENS) and Dynamic Compression Plating (DCP) are highly effective modalities for treating adolescent femoral shaft fractures, achieving excellent union rates. However, treatment must be individualized. TENS is the optimal, minimally invasive choice for younger adolescents with length-stable fractures, offering reduced operative morbidity and faster recovery. Conversely, DCP provides the absolute mechanical stability necessary for older adolescents and those with comminuted or length-unstable fractures, effectively preventing malunion and loss of reduction. Ultimately, successful management requires a tailored approach guided by the patient's age, weight, and specific fracture morphology.

AUTHOR CONTRIBUTIONS

The first and second authors conducted the primary study. The third & corresponding author independently supervised the study to minimize bias, assisted with data collection and interpretation, and prepared the manuscript.

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