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A Prospective Study of Functional Outcome Following Intramedullary Nailing in Diaphyseal Fractures of the Tibia

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Abstract

Background: Tibial diaphyseal fractures represent one of the most common long bone fractures requiring surgical intervention. Intramedullary nailing has evolved as the preferred treatment modality for displaced tibial shaft fractures, offering advantages of biomechanical stability, minimal soft tissue disruption, and early mobilization. However, comprehensive prospective data evaluating functional outcomes in the Indian population remains limited. This study prospectively evaluated the functional outcomes and complications following intramedullary nailing in tibial diaphyseal fractures.

Methods: This prospective observational study was conducted over 18 months, including 80 patients with closed and Gustilo type I open tibial diaphyseal fractures treated with reamed intramedullary interlocking nailing. Patients were followed for a minimum of 12 months. Functional outcomes were assessed using the Johner-Wruhs criteria at 6 and 12 months post-operatively. Radiological union, complications, and time to full weight-bearing were recorded. Statistical analysis was performed using SPSS version 25.0.

Results: The mean age of patients was 38.7 years with male predominance. Road traffic accidents accounted for 71.25% of injuries. Union was achieved in 92.5% of patients at a mean duration of 18.3 weeks. At 12-month follow-up, excellent to good functional outcomes were observed in 83.75% of patients according to Johner-

Wruhs criteria. Complications included anterior knee pain, superficial infection, malunion, and non-union. The mean time to full weight-bearing was 14.6 weeks.

Conclusion: Intramedullary nailing for tibial diaphyseal fractures demonstrated excellent functional outcomes with acceptable complication rates. The procedure allows early mobilization and satisfactory return to pre-injury functional status in the majority of patients.

Keywords: Tibial fractures, Intramedullary nailing, Diaphyseal fractures, Functional outcome, Johner-Wruhs criteria

Introduction

Tibial diaphyseal fractures constitute one of the most frequently encountered long bone injuries in orthopedic practice, accounting for approximately 4% of all fractures in adults and representing the most common long bone fracture requiring surgical management.[1] The tibia's subcutaneous location and limited soft tissue coverage make it particularly vulnerable to both direct and indirect trauma, resulting in a spectrum of injury patterns ranging from simple closed fractures to complex open fractures with significant soft tissue compromise. The unique anatomical characteristics of the tibia, including its triangular cross-section, minimal muscle coverage anteriorly, and tenuous blood supply to the middle third, present distinct challenges in achieving optimal fracture healing and functional recovery.[2]

The historical evolution of treatment modalities for tibial shaft fractures reflects the progressive understanding of fracture biology and biomechanical principles. Conservative management with cast immobilization, once considered the gold standard, has largely been supplanted by operative interventions due to several inherent limitations including prolonged immobilization, joint stiffness, muscle atrophy, malunion, and delayed return to functional activities. While conservative treatment may still have a role in undisplaced fractures, the overwhelming evidence supports surgical stabilization for displaced and unstable fracture patterns.[3] The advent of intramedullary fixation represented a paradigm shift in the management philosophy, offering biomechanically sound fixation while respecting the biological environment of fracture healing.

Intramedullary nailing has emerged as the treatment of choice for displaced tibial diaphyseal fractures, supported by extensive biomechanical research and clinical evidence demonstrating superior outcomes compared to alternative fixation methods.[4] The theoretical advantages of intramedullary nailing are multifaceted and well-established in the literature. The technique provides load-sharing rather than load-bearing fixation, allowing micromotion at the fracture site that promotes callus formation and secondary bone healing. The insertion technique preserves the periosteal blood supply, which is crucial for fracture healing, while the medullary blood supply reconstitutes during the healing process. The closed or minimally invasive approach reduces soft tissue stripping, decreases infection risk, and minimizes operative trauma. Furthermore, the central position of the implant within the medullary canal provides optimal biomechanical advantage with a shorter lever arm compared to extramedullary implants, resulting in reduced bending moments and superior resistance to deforming forces.[5]

The development of interlocking capabilities revolutionized intramedullary nailing by addressing the limitations of earlier unlocked designs. Proximal and distal interlocking screws provide rotational stability and control of length, effectively managing fracture patterns

that would otherwise be unsuitable for simple intramedullary fixation. This advancement expanded the indications for intramedullary nailing to include proximal and distal metaphyseal-diaphyseal junction fractures, comminuted fractures, and fractures with significant bone loss.[6] Contemporary interlocking nails incorporate various design features including multiple interlocking options, cannulation for guided insertion, and anatomically contoured profiles to match the anterior bow of the tibia, all contributing to improved surgical outcomes and reduced complications.

The technique of reamed versus unreamed nailing continues to generate considerable debate in the orthopedic literature, with proponents on both sides citing biomechanical and biological arguments. Reaming enlarges the medullary canal, allowing insertion of larger diameter nails that provide superior biomechanical stability and potentially faster union rates. However, reaming disrupts the endosteal blood supply and generates thermal necrosis, raising concerns about impaired healing, particularly in already compromised open fractures. Conversely, unreamed nailing preserves endosteal vascularity but necessitates smaller diameter implants with potentially reduced mechanical stability.[7] Current evidence suggests that in closed fractures and low-grade open fractures, reamed nailing offers advantages in terms of union rates and mechanical stability, while the selection between reamed and unreamed techniques should be individualized based on fracture characteristics and soft tissue status.

Functional outcome assessment following tibial fracture treatment encompasses multiple domains including fracture union, limb alignment, joint mobility, pain, return to work, and overall quality of life. Various scoring systems have been developed to standardize outcome evaluation, with the Johner-Wruhs criteria being one of the most widely utilized and validated instruments for tibial fracture assessment. This comprehensive scoring system evaluates multiple parameters including bony results, functional outcomes, and complications, providing a holistic assessment of treatment success.[8] The system categorizes outcomes into excellent, good, fair, and poor grades based on objective clinical and radiological parameters, facilitating meaningful comparison across studies and treatment modalities.

Despite the widespread adoption of intramedullary nailing as the standard of care for tibial diaphyseal fractures, the procedure is not without potential complications. Anterior knee pain represents the most frequently reported complication, occurring in 10-80% of patients depending on the surgical technique, nail design, and patient factors. The etiology of anterior knee pain remains incompletely understood but likely involves a combination of patellar tendon trauma during nail insertion, prominence of nail hardware, and infrapateleal fat pad fibrosis. Infection, although relatively uncommon in closed fractures, remains a devastating complication with rates ranging from 1-5% in most series. Malunion and non-union, while less common with modern interlocking techniques, still occur in 5-10% of cases, particularly in high-energy injuries with significant comminution or bone loss. Compartment syndrome, though primarily related to the initial injury rather than the surgical technique, requires vigilant monitoring and prompt fasciotomy when indicated. [9]

The Indian subcontinent presents unique epidemiological and demographic characteristics that influence fracture patterns and treatment outcomes. Road

traffic accidents constitute the predominant mechanism of injury, reflecting the growing burden of vehicular trauma in developing nations. The relatively younger age of presentation, delayed presentation in some cases due to limited healthcare access, and socioeconomic factors affecting rehabilitation compliance all impact the final functional outcomes. Furthermore, cultural factors including squatting and floor-sitting requirements for daily activities place additional demands on knee and ankle mobility, making comprehensive functional recovery particularly important in this population.[10]

The present prospective study was designed to comprehensively evaluate the functional outcomes following intramedullary nailing in tibial diaphyseal fractures within our institutional setting. By employing standardized assessment criteria, rigorous follow-up protocols, and detailed documentation of complications, this study aimed to contribute valuable data to the existing body of evidence regarding optimal management of these common yet challenging injuries. The findings provide insights into the effectiveness of intramedullary nailing in achieving fracture union, restoring limb function, and facilitating return to pre-injury activity levels in patients with tibial shaft fractures.

Aims and Objectives

The primary aim of this prospective study was to evaluate the functional outcomes in patients with tibial diaphyseal fractures treated with closed intramedullary interlocking nailing using the Johner-Wruhs criteria. The secondary objectives included assessment of radiological union time, evaluation of complications associated with the procedure, determination of time to full weight-bearing, analysis of factors influencing functional outcomes, and correlation of fracture patterns with clinical outcomes. The study aimed to provide comprehensive data on the efficacy and safety of intramedullary nailing as a treatment modality for tibial shaft fractures in our institutional setting. Additionally, the research sought to identify predictive factors for optimal outcomes and potential complications, thereby contributing to evidence-based clinical decision-making in the management of these common yet challenging fractures. The findings were intended to serve as a reference for orthopedic surgeons managing similar patient populations and to add to the existing body of literature on tibial fracture management.

Materials and Methods

Study Design and Setting

This prospective observational study was conducted in the Department of Orthopaedics at Raipur Institute of Medical Sciences, Raipur, Chhattisgarh, over a period of 18 months from January 2023 to June 2024. The study protocol was approved by the Institutional Ethics Committee, and written informed consent was obtained from all participants prior to enrollment. All procedures were performed in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments.

Sample Size and Study Population

The study included 80 patients with diaphyseal fractures of the tibia who met the predefined inclusion and exclusion criteria. Sample size calculation was performed based on previous studies reporting functional outcomes following intramedullary nailing, with a confidence interval of 95% and power of 80%. Consecutive patients presenting to the emergency department and outpatient clinics were screened for eligibility and enrolled after obtaining informed consent.

Inclusion Criteria

Patients aged between 18 and 65 years with closed or Gustilo type I open diaphyseal fractures of the tibia, fractures occurring within 2 weeks of presentation, patients fit for general or regional anesthesia, and patients willing to provide informed consent and comply with follow-up protocol were included in the study. Both unilateral and bilateral fractures were considered for inclusion.

Exclusion Criteria

Patients with pathological fractures, Gustilo type II and type III open fractures, fractures extending into the articular surface, patients with pre-existing deformity or arthritis of the ipsilateral limb, patients with active infection at the fracture site, polytrauma patients with associated life-threatening injuries, patients with peripheral vascular disease or neurological deficits in the affected limb, patients with significant medical comorbidities precluding surgery, and patients unwilling or unable to participate in follow-up were excluded from the study.

Pre-operative Assessment

All patients underwent comprehensive clinical examination including assessment of neurovascular status, soft tissue injury, and associated injuries. Anteroposterior and lateral radiographs of the entire tibia including knee and ankle joints were obtained. Fractures were classified according to the AO/OTA classification system. Routine laboratory investigations including complete blood count, renal function tests, blood glucose levels, and coagulation profile were performed. Pre-anesthetic evaluation was conducted, and risk stratification was performed using the American Society of Anesthesiologists physical status classification. In cases of open fractures, wound management with thorough irrigation and debridement was performed, and antibiotic prophylaxis was initiated according to institutional protocol.

Surgical Technique

All surgeries were performed by senior orthopedic surgeons with substantial experience in intramedullary nailing techniques. Patients were positioned supine on a radiolucent fracture table with the affected knee flexed to 90 degrees over a leg holder or with the use of a triangular support. The procedure was performed under general or spinal anesthesia with antibiotic prophylaxis administered 30 minutes prior to skin incision. A longitudinal midline incision approximately 4-5 cm in length was made from the inferior pole of the patella extending distally. The patellar tendon was split longitudinally or a medial parapatellar approach was utilized to access the tibial plateau. The entry point was created at the junction of the anterior border of the tibial plateau and the intercondylar eminence using an awl or cannulated drill. Fracture reduction was achieved by closed manipulation under fluoroscopic guidance and maintained with the aid of a reduction clamp when necessary. A guide wire was passed across the fracture site into the distal fragment under image intensification. Reaming of the medullary canal was performed using flexible reamers in 0.5 mm increments up to 1-1.5 mm larger than the anticipated nail diameter. An appropriately sized intramedullary nail was selected and inserted over the guide wire with gentle malleting. Proximal and distal interlocking was performed using the jig technique for proximal screws and free-hand technique under fluoroscopic guidance for distal screws. Two distal and two proximal interlocking bolts were used in all cases. Final position was confirmed with anteroposterior and lateral fluoroscopic images ensuring

satisfactory reduction and hardware position. The wound was closed in layers after thorough irrigation, and sterile dressing was applied.

Post-operative Management

Post-operative radiographs were obtained in all patients to document fracture reduction and implant position. Intravenous antibiotics were continued for 48 hours followed by oral antibiotics for 5 days. Adequate analgesia was provided, and limb elevation was maintained to reduce swelling. Active and passive range of motion exercises for the knee and ankle were initiated on the first post-operative day. Non-weight-bearing mobilization with walker or crutches was started on the second post-operative day as tolerated by the patient. Partial weight-bearing was permitted at 6 weeks post-operatively, and full weight-bearing was allowed based on clinical and radiological evidence of fracture healing. Suture removal was performed at 12-14 days post-operatively.

Follow-up Protocol

Patients were followed up at 6 weeks, 12 weeks, 6 months, and 12 months post-operatively. At each visit, clinical assessment including evaluation of wound healing, signs of infection, range of motion of knee and ankle joints, limb alignment, gait pattern, and functional status was performed. Radiological assessment with anteroposterior and lateral radiographs was conducted at each follow-up visit to evaluate fracture union, implant position, and complications. Union was defined as bridging callus across at least three cortices on orthogonal radiographs with absence of pain and tenderness at the fracture site and ability to bear full weight without support.

Outcome Assessment

Functional outcome was assessed using the Johner-Wruhs criteria at 6 months and 12 months post-operatively. The criteria evaluate multiple parameters including non-union, deformity, limitation of motion, pain, gait disturbance, osteoarthritis, neurological deficit, and infection. Based on these parameters, outcomes were classified as excellent, good, fair, or poor. Time to radiological union was recorded as the duration from surgery to achievement of radiographic union. Time to full weight-bearing was documented as the duration from surgery to independent full weight-bearing without support. Complications including infection, delayed union, non-union, malunion, anterior knee pain, hardware failure, and need for secondary procedures were systematically recorded.

Statistical Analysis

Data were entered into Microsoft Excel and analyzed using Statistical Package for Social Sciences version 25.0. Continuous variables were expressed as mean ± standard deviation, and categorical variables were expressed as frequencies and percentages. Chi-square test was used to analyze categorical variables, and Student's t-test was used for continuous variables. Analysis of variance was employed to compare means across multiple groups. Correlation analysis was performed to identify factors influencing functional outcomes. A p-value of less than 0.05 was considered statistically significant. Multivariate regression analysis was performed to identify independent predictors of functional outcome.

Results

The present prospective study included 80 patients with tibial diaphyseal fractures treated with closed intramedullary interlocking nailing. The demographic

characteristics revealed a mean age of 38.7±12.4 years with a range of 19 to 64 years. The age distribution showed that 32.5% of patients were in the 31-40 years age group, followed by 28.75% in the 21-30 years group, 21.25% in the 41-50 years group, 11.25% in the 51-60 years group, and 6.25% in the above 60 years group. There was a significant male predominance with 66 male patients accounting for 82.5% and 14 female patients accounting for 17.5% of the study population. The male to female ratio was 4.7:1, reflecting the higher incidence of traumatic injuries in males due to occupational and lifestyle factors.

Analysis of the mechanism of injury demonstrated that road traffic accidents were the predominant cause, accounting for 57 cases representing 71.25% of all injuries. Falls from height contributed to 15 cases accounting for 18.75%, direct blow injuries accounted for 6 cases representing 7.5%, and sports injuries accounted for 2 cases representing 2.5% of the total. The high proportion of road traffic accidents underscores the significant burden of vehicular trauma in the region. Regarding laterality, the right side was affected in 46 patients accounting for 57.5%, while the left side was affected in 34 patients accounting for 42.5%, showing no statistically significant difference in side predilection with a p-value of 0.18.

The fracture classification according to the AO/OTA system showed that type 42-A fractures representing simple fracture patterns were present in 34 cases accounting for 42.5%, type 42-B fractures representing wedge fractures were present in 28 cases accounting for 35%, and type 42-C fractures representing complex comminuted patterns were present in 18 cases accounting for 22.5%. Regarding the nature of injury, closed fractures constituted the majority with 72 cases representing 90%, while Gustilo type I open fractures accounted for 8 cases representing 10% of the study population. The mean duration from injury to surgery was 4.8±2.3 days with a range of 1 to 12 days, with most patients undergoing surgery within the first week after appropriate pre-operative optimization and soft tissue condition assessment.

Operative parameters revealed that the mean operative time was 87.6±15.4 minutes with a range of 65 to 125 minutes. The mean nail diameter used was 9.2±0.8 mm with sizes ranging from 8 mm to 11 mm, and the mean nail length was 340±24 mm with lengths ranging from 300 mm to 380 mm. All patients underwent reamed intramedullary nailing with two proximal and two distal interlocking screws in static mode. The mean intra-operative blood loss was 156±42 ml, which was considered acceptable for this procedure. Intra-operative fracture reduction was achieved successfully in all cases under fluoroscopic guidance without requiring open reduction in any patient.

The radiological union was assessed at regular follow-up intervals, and union was achieved in 74 patients representing 92.5% of cases at a mean duration of 18.3±3.7 weeks with a range of 14 to 28 weeks. Analysis of union time in relation to fracture pattern demonstrated that type 42-A fractures achieved union at a mean of 16.4±2.8 weeks, type 42-B fractures achieved union at a mean of 18.7±3.2 weeks, and type 42-C fractures achieved union at a mean of 21.6±4.5 weeks, showing statistically significant difference with a p-value of 0.001. Delayed union defined as absence of radiographic union at 20 weeks was observed in 8 patients accounting for 10%, and non-union at 12 months follow-up was documented in 6 patients accounting for 7.5%. The mean time to partial weight-bearing was 7.2±1.8 weeks, and

the mean time to full weight-bearing was 14.6±3.4 weeks.

Functional outcomes were assessed using the Johner-Wruhs criteria at 6 months and 12 months post-operatively. At 6 months follow-up, excellent outcome was achieved in 26 patients representing 32.5%, good outcome in 38 patients representing 47.5%, fair outcome in 12 patients representing 15%, and poor outcome in 4 patients representing 5%. At 12 months follow-up, there was improvement in functional outcomes with excellent results in 34 patients representing 42.5%, good results in 33 patients representing 41.25%, fair results in 9 patients representing 11.25%, and poor results in 4 patients representing 5%. Combining excellent and good outcomes, satisfactory functional results were achieved in 83.75% of patients at final follow-up, demonstrating the efficacy of intramedullary nailing in restoring functional capacity.

Range of motion assessment at final follow-up showed that the mean knee flexion was 128.4±12.6 degrees with a range of 95 to 140 degrees, and the mean ankle dorsiflexion was 14.2±3.8 degrees with a range of 5 to 20 degrees. Ankle plantarflexion averaged 38.6±6.4 degrees with a range of 20 to 45 degrees. Comparison with the contralateral limb revealed that 71.25% of patients achieved within 10 degrees of normal knee range of motion, and 67.5% achieved within 5 degrees of normal ankle range of motion, indicating satisfactory joint mobility preservation in the majority of patients.

Analysis of angular deformity at final follow-up demonstrated that 68 patients representing 85% had acceptable alignment within 5 degrees of varus or valgus angulation, while 12 patients representing 15% had greater than 5 degrees of angular deformity. Regarding rotational alignment, 74 patients representing 92.5% had acceptable rotational alignment within 10 degrees, while 6 patients representing 7.5% had rotational malunion exceeding 10 degrees. Leg length discrepancy measurement revealed that 70 patients representing 87.5% had shortening of less than 1 cm, 8 patients representing 10% had shortening between 1 to 2 cm, and 2 patients representing 2.5% had shortening greater than 2 cm.

Complications were systematically documented and analyzed throughout the follow-up period. Anterior knee pain was the most common complication, occurring in 28 patients representing 35% at 6 months follow-up, which decreased to 16 patients representing 20% at 12 months follow-up. The pain was graded as mild in 11 patients representing 13.75%, moderate in 4 patients representing 5%, and severe in 1 patient representing 1.25% at final follow-up. Superficial wound infection occurred in 4 patients representing 5%, all of which resolved with appropriate antibiotic therapy and local wound care without requiring implant removal. Deep infection requiring debridement was not encountered in any case. Non-union developed in 6 patients representing 7.5%, of which 4 underwent exchange nailing with bone grafting and 2 were managed with dynamization. Malunion with clinically significant angular deformity was observed in 5 patients representing 6.25%, including 3 cases of varus malunion and 2 cases of valgus malunion. Implant-related complications included screw back-out in 2 patients representing 2.5%, which required removal, and implant breakage was not observed in any case. Other complications included transient peroneal nerve neuropraxia in 2 patients representing 2.5%, both of which recovered spontaneously within 3 months, and compartment syndrome requiring fasciotomy in 1 patient

representing 1.25% in the immediate post-operative period.

Statistical analysis was performed to identify factors influencing functional outcomes. Age was found to have a significant correlation with functional outcome, with patients younger than 40 years demonstrating better outcomes compared to those above 40 years with a p-value of 0.03. Fracture pattern showed significant association with functional outcome, with simple fracture patterns (type 42-A) achieving better results compared to complex comminuted fractures (type 42-C) with a p-value of 0.002. The mechanism of injury also demonstrated significant correlation, with low-energy injuries showing better functional outcomes compared to high-energy road traffic accidents with a p-value of 0.018. Time from injury to surgery did not show statistically significant correlation with functional outcome with a p-value of 0.24. Gender did not significantly influence the final functional outcome with a p-value of 0.31. The presence of complications, particularly non-union and malunion, showed strong negative correlation with functional outcome with a p-value of less than 0.001.

Multivariate regression analysis identified fracture pattern, patient age, and achievement of union as independent predictors of functional outcome. The overall complication rate in the present study was 46.25%, which included all minor and major complications. However, major complications requiring secondary procedures occurred in only 13.75% of cases. The return to pre-injury occupation was achieved in 68 patients representing 85% at a mean duration of 7.4±2.6 months post-operatively. Patient satisfaction assessed on a visual analog scale showed a mean score of 8.2±1.6 out of 10, indicating high levels of satisfaction with the treatment outcome.

Table 1: Demographic Characteristics and Injury Pattern

Parameter	Category	Number (n)	Percentage (%)
Age Groups	18-30 years	23	28.75
	31-40 years	26	32.5
	41-50 years	17	21.25
	51-60 years	9	11.25
	>60 years	5	6.25
Gender	Male	66	82.5
	Female	14	17.5
Mechanism of Injury	Road Traffic Accident	57	71.25
	Fall from Height	15	18.75
	Direct Blow	6	7.5
	Sports Injury	2	2.5
Laterality	Right Side	46	57.5

Parameter	Category	Number (n)	Percentage (%)
	Left Side	34	42.5
AO/OTA Classification	Type 42-A	34	42.5
	Type 42-B	28	35.0
	Type 42-C	18	22.5
Fracture Type	Closed	72	90.0
	Open (Gustilo Type I)	8	10.0

Table 2: Operative Parameters and Union Characteristics

Parameter	Mean ± SD	Range
Operative Time (minutes)	87.6 ± 15.4	65 - 125
Nail Diameter (mm)	9.2 ± 0.8	8 - 11
Nail Length (mm)	340 ± 24	300 - 380
Intra-operative Blood Loss (ml)	156 ± 42	80 - 240
Time to Union (weeks)	18.3 ± 3.7	14 - 28
Time to Partial Weight-Bearing (weeks)	7.2 ± 1.8	4 - 12
Time to Full Weight-Bearing (weeks)	14.6 ± 3.4	10 - 24

Union Status

- Union Achieved: 74 patients (92.5%)
- Delayed Union: 8 patients (10%)
- Non-union: 6 patients (7.5%)

Table 3: Union Time According to Fracture Pattern

Fracture Type	Number (n)	Mean Union Time (weeks)	Standard Deviation	p-value
Type 42-A (Simple)	34	16.4	± 2.8	0.001
Type 42-B (Wedge)	28	18.7	± 3.2	
Type 42-C (Complex)	18	21.6	± 4.5	

Table 4: Functional Outcome According to Johner-Wruhs Criteria

Outcome Grade	6 Months Follow-up		12 Months Follow-up	
	Number (n)	Percentage (%)	Number (n)	Percentage (%)
Excellent	26	32.5	34	42.5
Good	38	47.5	33	41.25

Outcome Grade	6 Months Follow-up		12 Months Follow-up	
Fair	12	15.0	9	11.25
Poor	4	5.0	4	5.0
Satisfactory (Excellent + Good)	64	80.0	67	83.75

Table 5: Range of Motion and Alignment Parameters at 12 Months

Parameter	Mean ± SD	Range	Within Normal Limits
Knee Flexion (degrees)	128.4 ± 12.6	95 - 140	57 patients (71.25%)
Ankle Dorsiflexion (degrees)	14.2 ± 3.8	5 - 20	54 patients (67.5%)
Ankle Plantarflexion (degrees)	38.6 ± 6.4	20 - 45	52 patients (65%)
Angular Deformity <5°	-	-	68 patients (85%)
Rotational Alignment <10°	-	-	74 patients (92.5%)
Leg Length Discrepancy <1 cm	-	-	70 patients (87.5%)

Table 6: Complications and Secondary Procedures

Complication	Number (n)	Percentage (%)	Management
Anterior Knee Pain (at 12 months)	16	20.0	Conservative
Superficial Infection	4	5.0	Antibiotics
Deep Infection	0	0	-
Non-union	6	7.5	Exchange nailing (4), Dynamization (2)
Malunion	5	6.25	Observation (3), Corrective osteotomy (2)
Screw Back-out	2	2.5	Screw removal
Implant Breakage	0	0	-
Peroneal Nerve Neuropraxia	2	2.5	Spontaneous recovery
Compartment Syndrome	1	1.25	Fasciotomy
Total Major Complications	11	13.75	
Overall Complication Rate	37	46.25	

Discussion

The present prospective study evaluated the functional outcomes following intramedullary nailing in 80 patients with tibial diaphyseal fractures. The demographic profile demonstrated a mean age of 38.7 years with significant male predominance, which is consistent with established literature on tibial fractures. Similar age and gender distribution was reported by Karladani et al. who found a mean age of 39.3 years with 75% male patients in their series of tibial shaft fractures.[11] The preponderance of

males in the working age group reflects the higher exposure to traumatic injuries due to occupational hazards and road traffic accidents. The male to female ratio of 4.7:1 in the current study closely approximates the findings of Guo et al. who reported a ratio of 4.2:1 in their multicenter study on tibial fractures.[12]

Road traffic accidents constituted the predominant mechanism of injury accounting for 71.25% of cases in the present study, which underscores the significant burden of vehicular trauma in developing nations with rapidly increasing motorization and inadequate road safety infrastructure. This finding parallels the observations of Prasad et al. who reported that road traffic accidents accounted for 68% of tibial shaft fractures in their Indian patient cohort.[13] The high proportion of high-energy injuries has important implications for fracture pattern complexity, soft tissue damage, and ultimate functional outcomes. In contrast, studies from developed nations report a more balanced distribution between high-energy and low-energy mechanisms, reflecting differences in injury epidemiology across geographic regions.[14]

The fracture pattern distribution in the current study showed that simple fracture patterns constituted 42.5%, wedge fractures 35%, and complex comminuted fractures 22.5% according to the AO/OTA classification. This distribution is comparable to the series reported by Beytemur et al. who documented similar proportions of fracture complexity in their cohort of 124 patients treated with intramedullary nailing.[15] The preponderance of closed fractures at 90% reflects the selection criteria employed in the study, which excluded higher grade open fractures that typically require alternative management strategies. The inclusion of only Gustilo type I open fractures ensures comparability of outcomes and minimizes the confounding effect of severe soft tissue injury on functional results.

The operative parameters in the present study demonstrated a mean operative time of 87.6 minutes, which is within the acceptable range for closed intramedullary nailing procedures. Comparable operative times were reported by Kumar et al. who documented a mean duration of 82 minutes in their series of 60 patients.[16] The mean intra-operative blood loss of 156 ml represents minimal surgical trauma and supports the minimally invasive nature of the procedure. All procedures were successfully completed using closed reduction techniques without requiring open reduction, demonstrating the effectiveness of fluoroscopic guidance and appropriate surgical technique in achieving satisfactory fracture alignment.

The radiological union rate of 92.5% achieved at a mean duration of 18.3 weeks in the current study compares favorably with published literature on intramedullary nailing outcomes. Court-Brown et al. reported union rates of 95% at a mean of 17.2 weeks in their large series of closed tibial fractures treated with reamed intramedullary nailing.[17] The slightly longer union time in the present study may be attributed to the higher proportion of complex fracture patterns and the demographic characteristics of the study population. The statistically significant correlation between fracture pattern complexity and union time, with type 42-C fractures requiring 21.6 weeks compared to 16.4 weeks for type 42-A fractures, confirms the established principle that comminuted fractures heal more slowly due to greater periosteal disruption and compromised fracture biology.[18]

The delayed union rate of 10% and non-union rate of 7.5% in the present study fall within the expected range

for tibial fractures treated with intramedullary nailing. A systematic review by Bhandari et al. reported non-union rates ranging from 3% to 12% across multiple studies, with higher rates observed in complex fracture patterns and high-energy injuries.[19] However, these rates are higher than those reported by Kretteck et al. who documented non-union in only 2.8% of patients, possibly reflecting differences in patient selection criteria and fracture severity.[20] All cases of non-union in the current study were successfully managed with exchange nailing and bone grafting, ultimately achieving union without resorting to alternative fixation methods.

The functional outcomes assessed using the Johner-Wruhs criteria demonstrated excellent to good results in 83.75% of patients at 12-month follow-up, indicating satisfactory restoration of limb function in the majority of patients. These results are consistent with those reported by Johner and Wruhs in their original description of the outcome assessment system, where they reported 82% excellent to good outcomes in their series of 175 tibial fractures.[21] However, the outcomes in the present study are superior to those reported by Obremskey et al. who achieved satisfactory outcomes in only 72% of patients, possibly due to the inclusion of higher grade open fractures in their cohort.[22] The improvement in functional scores from 6 months to 12 months follow-up demonstrates the continued recovery and adaptation that occurs during the second half of the first post-operative year, emphasizing the importance of extended follow-up in outcome assessment.

The correlation between fracture pattern and functional outcome was statistically significant in the present study, with simple fracture patterns achieving superior results compared to complex comminuted fractures. This finding is corroborated by multiple studies demonstrating that fracture complexity is a major determinant of functional outcome. Im and Tae reported that complex fracture patterns were associated with a threefold increased risk of poor functional outcome in their multivariate analysis of 187 tibial fractures.[23] The biological disruption associated with comminuted fractures, including greater soft tissue damage and compromised vascularity, contributes to prolonged recovery and reduced functional capacity.

Patient age emerged as a significant predictor of functional outcome in the current study, with patients younger than 40 years demonstrating superior results. This age-related difference in outcomes has been well documented in the orthopedic trauma literature and is attributed to multiple factors including better bone quality, enhanced healing capacity, superior rehabilitation potential, and higher pre-injury functional status in younger individuals. Weiss et al. conducted a detailed analysis of age-related outcomes in tibial fractures and found that patients over 50 years had significantly lower functional scores and higher complication rates compared to younger cohorts.[24]

The complication profile in the present study revealed anterior knee pain as the most common adverse outcome, affecting 20% of patients at final follow-up. This complication rate is within the wide range reported in literature, with incidence varying from 10% to 80% depending on the assessment method and follow-up duration. Song et al. performed a comprehensive analysis of anterior knee pain following tibial nailing and identified multiple risk factors including patellar tendon splitting approach, prominent proximal nail hardware, and obesity.[25] The decrease in anterior knee pain prevalence from 35% at 6 months to 20% at 12 months in the current study indicates that this

complication tends to improve with time, although a subset of patients experiences persistent symptoms requiring long-term management.

The superficial infection rate of 5% in the current study is comparable to rates reported in most series of closed tibial fractures treated with intramedullary nailing. The absence of deep infections requiring implant removal reflects appropriate perioperative antibiotic prophylaxis, meticulous surgical technique, and early identification and treatment of wound complications. In contrast, studies including high-grade open fractures report substantially higher infection rates, emphasizing the importance of soft tissue status as a primary determinant of infection risk. The malunion rate of 6.25% in the present study, while within acceptable limits, highlights the technical challenges in maintaining perfect alignment during closed nailing, particularly in comminuted and unstable fracture patterns.[26]

Range of motion outcomes in the current study demonstrated preservation of knee and ankle mobility in the majority of patients, with 71.25% achieving near-normal knee flexion and 67.5% achieving near-normal ankle dorsiflexion. These results are comparable to those reported by Lefaivre et al. who documented similar joint mobility outcomes in their series of 156 patients followed for 2 years post-operatively.[27] The satisfactory joint mobility reflects the advantage of early mobilization facilitated by stable intramedullary fixation, which prevents the joint stiffness commonly observed with prolonged immobilization in conservative treatment protocols.

The return to pre-injury occupation in 85% of patients at a mean duration of 7.4 months represents a significant socioeconomic benefit of intramedullary nailing, particularly in the working-age population constituting the majority of the study cohort. This outcome is superior to historical results with conservative management, where prolonged immobilization often resulted in delayed return to work and reduced earning capacity. The high patient satisfaction score of 8.2 out of 10 on visual analog scale reflects the overall success of the treatment in meeting patient expectations and restoring functional independence.[28]

Comparison with alternative fixation methods demonstrates the advantages of intramedullary nailing over external fixation and plate osteosynthesis for tibial diaphyseal fractures. External fixation, while useful in specific clinical scenarios such as severe open fractures and polytrauma, is associated with higher rates of pin tract infection, malunion, refracture after frame removal, and patient dissatisfaction with the external hardware. Plate osteosynthesis requires extensive soft tissue dissection, disrupts periosteal blood supply, and carries increased infection risk in the minimally covered anterior tibial surface. Meta-analyses comparing different fixation methods consistently demonstrate superior outcomes with intramedullary nailing in terms of union rates, functional outcomes, and complication profiles.[29]

The present study has several strengths including prospective design, standardized surgical technique, rigorous follow-up protocol, validated outcome assessment tools, and comprehensive complication documentation. However, certain limitations must be acknowledged. The sample size of 80 patients, while adequate for statistical analysis, is relatively modest compared to large multicenter studies. The exclusion of high-grade open fractures limits generalizability to the entire spectrum of tibial trauma. The follow-up duration of 12 months, while sufficient for assessing union and

early functional outcomes, may not capture long-term complications such as post-traumatic arthritis and implant-related issues. The lack of a control group treated with alternative methods precludes direct comparative analysis of treatment modalities.[30]

Future research directions should include long-term follow-up studies extending beyond 2 years to evaluate delayed complications and late functional deterioration, comparative randomized controlled trials between reamed and unreamed nailing techniques, investigations into optimal management of anterior knee pain following nailing, cost-effectiveness analyses comparing intramedullary nailing with alternative treatment modalities, and development of predictive models for identifying patients at risk of poor outcomes who may benefit from enhanced rehabilitation protocols or alternative treatment strategies.

Conclusion

The present prospective study comprehensively evaluated the functional outcomes following intramedullary nailing in tibial diaphyseal fractures and demonstrated that this treatment modality achieves excellent to good results in the majority of patients. The union rate of 92.5% at a mean duration of 18.3 weeks confirms the efficacy of intramedullary nailing in promoting fracture healing through biomechanically stable fixation while preserving the biological environment. The functional outcome assessment using the Johner-Wruhs criteria revealed satisfactory results in 83.75% of patients at 12-month follow-up, indicating successful restoration of limb function and return to pre-injury activity levels in most cases.

The study identified several factors significantly influencing functional outcomes, including fracture pattern complexity, patient age, and achievement of bony union. Simple fracture patterns and younger age groups demonstrated superior outcomes, while complex comminuted fractures required longer healing times and showed increased complication rates. The complication profile was acceptable, with anterior knee pain being the most common adverse outcome, which showed tendency to improve with time. The absence of deep infections and low rates of malunion and non-union reflect the advantages of the minimally invasive surgical approach and biomechanically sound fixation provided by intramedullary nailing. The results of the present study support intramedullary nailing as the treatment of choice for displaced tibial diaphyseal fractures, offering predictable outcomes with early mobilization, reduced morbidity, and satisfactory functional recovery. The procedure allows patients to return to their pre-injury occupation and activities with acceptable limb alignment and joint mobility. The high patient satisfaction scores further validate the effectiveness of this treatment approach in meeting patient expectations and improving quality of life following tibial fractures.

Future research should focus on long-term outcome assessment, identification of modifiable risk factors for complications, development of strategies to minimize anterior knee pain, and refinement of surgical techniques to optimize fracture reduction and implant positioning. Continued prospective studies with larger sample sizes and extended follow-up periods will contribute to the evolving understanding of optimal management strategies for tibial diaphyseal fractures and help establish evidence-based guidelines for clinical practice.

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