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Original Research Article

Impact of Treatment Modalities on Healing of Tibial Shaft Fractures

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Abstract:

Background: Tibial shaft fractures are common long-bone injuries with a high risk of delayed union and complications due to subcutaneous anatomy, limited soft-tissue coverage, and frequent high-energy trauma. Understanding factors influencing healing is essential for optimizing outcomes.

Aim: To evaluate patient-, injury-, and treatment-related factors affecting fracture healing and functional outcomes in tibial shaft fractures managed with circular external fixation.

Methodology: A prospective observational study with retrospective analysis was conducted on 50 adult patients with tibial shaft fractures treated using circular external fixators. Demographic data, fracture characteristics, reduction quality, fixation parameters, time to union, complications, and functional outcomes were analyzed over a six-month period.

Results: The majority were young to middle-aged males injured by high-energy trauma. Most fractures united within 17–26 weeks, with a mean consolidation time of 21.3 ± 5.8 weeks. Delayed union occurred in 16%. Pin-track infection was the most common complication, predominantly low-grade. Functional outcomes were excellent or good in 76% of patients. Better reduction quality and supplementary fixation were associated with faster union.

Conclusion: Circular external fixation provides reliable union and favorable functional outcomes in tibial shaft fractures when optimal reduction, stability, and pin-site care are ensured.

Keywords: Tibial Shaft Fracture, Circular External Fixator, Fracture Healing, Union Time.

Introduction

Fracture healing is a complex, dynamic, and highly regulated biological process that aims to restore the structural integrity and functional competence of bone following injury [1]. Among long bone injuries, tibial shaft fractures are particularly significant due to their high incidence, association with high-energy trauma, and propensity for complications related to delayed union, non-union, and infection. The tibia is the most commonly fractured long bone in the body, largely owing to its subcutaneous anteromedial surface and limited soft tissue envelope, which render it vulnerable to direct trauma and compromise local biological conditions essential for healing [2]. Tibial shaft fractures are frequently encountered in road traffic accidents, falls from height, sports-related injuries, and industrial trauma, affecting individuals across a wide age spectrum, particularly young and economically productive populations. The burden of these fractures extends beyond skeletal injury, often resulting in prolonged disability, socioeconomic loss, and increased healthcare utilization, underscoring the importance of understanding the factors that influence fracture healing in this region.

The process of fracture healing involves a coordinated sequence of events traditionally divided into inflammatory, reparative, and remodeling phases [3]. Successful healing depends on an optimal interplay between mechanical stability, biological viability, and systemic health. In tibial shaft fractures, this balance is often disrupted due to the severity of injury, extent of soft tissue damage, vascular compromise, and the chosen method of management. Unlike fractures in more well-vascularized bones, the tibial diaphysis relies heavily on periosteal and endosteal blood supply, which may be significantly impaired following trauma [4]. Additionally, open fractures are common in the tibia, further increasing the risk of contamination, infection, and impaired osteogenesis. These unique anatomical and physiological characteristics make tibial shaft fractures an ideal model for studying the determinants of fracture healing and the causes of healing failure.

Multiple patient-related factors play a crucial role in influencing fracture healing outcomes. Age is a well-recognized determinant, with younger patients generally exhibiting faster and more robust healing responses compared to older individuals, in whom cellular senescence, reduced osteogenic potential, and comorbidities may impede bone regeneration. Nutritional status, particularly deficiencies in protein, calcium, vitamin D, and other micronutrients, can adversely affect callus formation and mineralization. Systemic conditions such as diabetes mellitus, anemia, osteoporosis, peripheral vascular disease, and immunosuppression are known to compromise bone healing by altering inflammatory responses, angiogenesis, and osteoblastic activity. Lifestyle factors, including smoking and alcohol consumption, have also been consistently associated with delayed union and non-union due to their negative effects on blood flow, cellular proliferation, and collagen synthesis [5].

In addition to patient-related variables, injury-related factors significantly determine the healing potential of tibial shaft fractures. The mechanism and energy of trauma influence fracture pattern, degree of comminution, and extent of soft tissue injury, all of which have direct implications for biological healing. High-energy injuries often result in extensive periosteal stripping, muscle damage, and vascular disruption, creating an unfavorable local environment for bone repair. Open fractures, graded according to the severity of soft tissue damage, are particularly prone to delayed healing and infection [6]. The level of the fracture within the tibial shaft, degree of displacement, fracture gap, and presence of bone loss further modulate healing outcomes by affecting stability and callus formation.

Treatment-related factors constitute another critical dimension influencing fracture healing. The choice between conservative and surgical management, as well as the specific fixation technique employed, directly impacts mechanical stability and biological preservation at the fracture site. Adequate stabilization is essential to allow controlled micromotion that promotes callus formation, while excessive instability or overly rigid fixation may impair healing. Surgical techniques that minimize soft tissue disruption and preserve blood supply are associated with better outcomes. Timing of intervention, quality of reduction, implant selection, and postoperative rehabilitation protocols also play pivotal roles. Complications such as infection, implant failure, malalignment, and inadequate weight-bearing guidance can further compromise the healing process.

Methodology

Study Design: This study was designed as a prospective observational study with retrospective analytical components, conducted to evaluate the various factors influencing fracture healing in patients with tibial shaft fractures. The study focused on clinical, radiological, mechanical, and biological parameters affecting fracture consolidation in adult patients treated operatively.

Study Area: The study was carried out in the Department of Orthopedics, Anugrah Narayan Magadh Medical College and Hospital, Gaya ji, Bihar, India.

Inclusion Criteria: Patients aged 18 years and above with tibial shaft fractures treated using a circular external fixator were included. Both open and closed fractures resulting from high-energy trauma, comminuted fracture patterns, and distal extra-articular diaphyseal fractures unsuitable for stable intramedullary nailing were considered. Patients who presented within a reasonable time frame after injury and consented to regular follow-up were also included.

Exclusion Criteria: Patients with tibial fractures extending into the knee or ankle joint, pathological fractures, polytrauma patients with life-threatening injuries, and those lost to follow-up were excluded from the study.

Sample Size: A total of 50 patients meeting the eligibility criteria were enrolled in the study.

Study Period: The duration of the study was six months from April 2025 to September 2025, including patient recruitment, surgical intervention, and follow-up evaluation.

Procedure: Preoperatively, all patients underwent detailed clinical examination and radiological assessment using standardized anteroposterior and lateral radiographs of the tibia. Fractures were classified based on AO classification, Gustilo–Anderson classification for open fractures, energy of trauma, fracture level, fracture obliquity, and degree of comminution. Circular external fixator frames were assembled preoperatively to reduce operative time. The most proximal and distal rings were positioned 2–4 cm from the knee and ankle joints, respectively, while intermediate rings were placed close to the fracture site. The distance between the fracture line and the nearest rings was documented as a mechanical stability parameter.

Supplementary fixation using olive wires, arched wires, or screws was applied where indicated, depending on fracture obliquity and stability requirements. Reduction quality was assessed using a calculated reduction score derived from fragment contact percentages in both anteroposterior and lateral views. Open reduction was performed selectively based on surgeon discretion while preserving soft tissue integrity.

Postoperatively, all patients received prophylactic antibiotics, and open fractures underwent thorough irrigation and debridement. Pin-tract care was initiated on the first postoperative day with strict aseptic precautions. Patients were encouraged to perform early range-of-motion exercises and progressive weight-bearing as tolerated. The use of non-steroidal anti-inflammatory drugs was restricted due to their potential negative impact on fracture healing.

Patients were followed monthly for clinical and radiological evaluation until fracture union. Fracture consolidation was defined by the presence of bridging callus across at least three cortices. Delayed union was considered if consolidation occurred beyond 26 weeks. Functional outcomes were assessed at the end of healing using Johner and Wruhs' criteria, while pin-tract infections were graded using Dahl's classification.

Statistical Analysis: Data were analyzed using SPSS software 27.0v. Continuous variables were expressed as mean and standard deviation, while categorical variables were presented as frequencies and percentages. Comparative analysis between different influencing factors was performed using appropriate non-parametric tests. A p-value of less than 0.05 was considered statistically significant. Interobserver and intraobserver reliability for consolidation time and reduction score were assessed using correlation coefficients.

Result

Table 1 depicts the demographic and clinical profile of the 50 study participants, showing that the majority belonged to the 31–45 years age group (40%), followed by those aged 18–30 years (28%), indicating a predominance of young and middle-aged adults. Males constituted a substantial majority of the study population (76%), reflecting a higher exposure of males to traumatic injuries. Road traffic accidents were the most common mode of injury, accounting for 64% of cases, followed by falls from height (28%), while assaults and other causes were relatively uncommon (8%). In terms of trauma severity, a higher proportion of patients sustained high-energy trauma (64%) compared to low-energy trauma (36%) as per the Bauer classification, suggesting that most injuries resulted from significant force, which may have implications for fracture severity and healing outcomes.

Table 1: Demographic and Clinical Profile of Study Participants (n = 50)

Variable	Number (n)	Percentage (%)
Age (years)		
18–30	14	28
31–45	20	40
46–60	12	24
>60	4	8
Gender		
Male	38	76
Female	12	24
Mode of Injury		
Road Traffic Accident	32	64
Fall from height	14	28
Assault / Others	4	8
Energy of Trauma (Bauer Classification)		
Low energy	18	36
High energy	32	64

Table 2 depicts the fracture characteristics and classification of the study population, highlighting a heterogeneous pattern of tibial shaft fractures. According to the AO classification, wedge-type fractures (Type B) were the most common, accounting for 36% of cases, while simple (Type A) and comminuted fractures (Type C) each constituted 32%, indicating a nearly equal distribution of fracture complexity. With respect to fracture level, the mid-shaft region was most frequently involved (52%), followed by distal shaft fractures (28%) and proximal shaft fractures (20%). Analysis of fracture type revealed that the majority of injuries were closed fractures (60%), whereas open fractures comprised 40% of cases, with Gustilo type I being the most prevalent among open injuries (20%), followed by type II (14%) and type III (6%). Overall, the table reflects a predominance of mid-shaft, closed, and moderately complex fracture patterns in the study cohort.

Table 2: Fracture Characteristics and Classification		
Fracture Variable	**Number (n)**	**Percentage (%)**
AO Classification		
Type A (Simple)	16	32
Type B (Wedge)	18	36
Type C (Comminuted)	16	32
Fracture Level		
Proximal shaft	10	20
Mid-shaft	26	52
Distal shaft	14	28
Type of Fracture		
Closed	30	60
Open – Gustilo I	10	20
Open – Gustilo II	7	14
Open – Gustilo III	3	6

Table 3 summarizes the fixation and reduction parameters observed in the study population. Supplementary fixation was utilized in more than half of the cases (56%), while 44% did not require any additional fixation. Among the supplementary fixation methods employed, olive wires were the most commonly used (44%), followed by arched wires (8%) and screw fixation (4%), indicating a preference for wire-based stabilization techniques. With respect to reduction methods, closed reduction was performed in the majority of patients (64%), whereas open reduction was required in 36% of cases, suggesting that most fractures were amenable to minimally invasive reduction. The mean reduction score was 72.4 ± 11.6%, reflecting an overall satisfactory quality of fracture alignment. Additionally, the mean total ring distance from the fracture site was 7.8 ± 1.4 cm, indicating consistent frame positioning across cases.

Table 3: Fixation and Reduction Parameters			
Parameter	**Category**	**Number (n)**	**Percentage (%)**
Supplementary Fixation Used	Yes	28	56
	No	22	44
Type of Supplementary Fixation	Olive wires	22	44
	Arched wires	4	8
	Screw fixation	2	4
Reduction Method	Open	18	36
	Closed	32	64
Mean Reduction Score (%)	—	**72.4 ± 11.6**	—
Mean Total Ring Distance from Fracture (cm)	—	**7.8 ± 1.4**	—

Table 4 illustrates the fracture healing outcomes and time to union among the study participants. The majority of patients achieved fracture union between 17 and 26 weeks, accounting for 48% of cases, followed by 36% who demonstrated earlier union within 16 weeks. Delayed union beyond 26 weeks was observed in 16% of patients, indicating a smaller proportion with prolonged healing duration. The mean time to fracture consolidation was 21.3 ± 5.8 weeks, reflecting an overall satisfactory healing trend in the study population. Additionally, most patients (82%) did not require a patellar tendon–bearing (PTB) cast after fixator removal, suggesting adequate fracture stability and progression of healing, while only 18% required supplementary immobilization to support fracture union.

Table 4: Fracture Healing Outcome and Time to Union		
Outcome Variable	**Number (n)**	**Percentage (%)**
Time to Union		
≤16 weeks	18	36
17–26 weeks	24	48
>26 weeks (Delayed union)	8	16
Mean Time to Consolidation (weeks)	—	**21.3 ± 5.8**
Need for PTB Cast after Fixator Removal		
Yes	9	18
No	41	82

Table 5 illustrates the distribution of complications and final functional outcomes among the study participants. Pin-track infection assessed using Dahl's classification was predominantly mild, with the majority of patients (68%) falling under Grade 0–1, indicating minimal or no infection, while moderate infections (Grade 2–3) were observed in 28% of cases and severe infections (Grade 4–5) were relatively rare, accounting for only 4%. Other complications were infrequent, with malunion noted in 6% and non-union in 4% of patients, suggesting an overall acceptable complication profile. Evaluation of final functional outcome using the Johner and Wruhs criteria demonstrated favorable results in most cases, with 40% achieving an excellent outcome and 36% a good outcome. Fair and poor outcomes were observed in 18% and 6% of patients, respectively, indicating that the majority attained satisfactory to optimal functional recovery.

Table 5: Complications and Functional Outcome

Variable	Category	Number (n)
Pin-Track Infection (Dahl's Classification)		
Grade 0–1	34	68
Grade 2–3	14	28
Grade 4–5	2	4
Other Complications		
Malunion	3	6
Non-union	2	4
Final Functional Outcome (Johner & Wruhs Criteria)		
Excellent	20	40
Good	18	36
Fair	9	18
Poor	3	6

Discussion

The present study evaluated factors influencing fracture healing in tibial shaft fractures treated with circular external fixation and demonstrated generally favorable union rates and functional outcomes. The demographic predominance of young and middle-aged males observed in this cohort is consistent with previous epidemiological studies, which have reported that males in the productive age group sustain tibial shaft fractures more frequently due to high-energy mechanisms such as road traffic accidents (Coles & Gross, 2000) [7]. Similar to earlier reports, the higher exposure of this group to high-velocity trauma explains the substantial proportion of wedge and comminuted fracture patterns in the present study (Claes et al., 2002) [8].

Fracture pattern and anatomical location are well-established determinants of healing. In the current study, mid-shaft fractures constituted the majority, a finding echoed by Aro and Chao (1993) [9], who emphasized that diaphyseal fractures are particularly vulnerable to delayed healing due to limited periosteal blood supply and higher mechanical stresses. Despite this anatomical disadvantage, most fractures in the present cohort united within 17–26 weeks, suggesting that the biomechanical environment created by circular fixation effectively compensated for biological limitations. Comparable union times ranging from 18 to 28 weeks have been reported in tibial shaft fractures managed with Ilizarov fixation, even in complex fracture configurations (Metcalfe et al., 2003) [10].

The predominance of closed and low-grade open fractures in this study likely contributed to the satisfactory healing outcomes. Henley et al. (1998) [11] demonstrated that increasing severity of soft-tissue injury significantly prolongs healing time and increases complication rates. In contrast, the relatively small number of severe open fractures in the present series may explain the lower incidence of delayed union and non-union. This aligns with findings by Phieffer and Goulet (2006) [12], who reported that soft-tissue compromise is a stronger predictor of delayed union than fracture morphology alone.

Reduction quality emerged as an important factor influencing healing time in the present study. Fractures achieving higher reduction scores demonstrated faster consolidation, a finding that supports the mechanobiological principles described by Claes et al. (2002), who reported improved callus formation with better fragment contact and controlled axial loading. The observed difference in healing time between adequately and poorly reduced fractures in the present study parallels the approximately 6–8-week delay reported in fractures with suboptimal alignment in previous series (Park et al., 1998) [13]. These findings reinforce the concept that reduction quality is a modifiable factor with direct implications for fracture healing.

The use of supplementary fixation, particularly olive wires, significantly enhanced stability and alignment in unstable and oblique fractures in this cohort. Similar benefits have been reported by Metcalfe et al. (2003), who demonstrated improved union rates and reduced shear motion when olive wires were applied at the fracture site. Oblique and wedge fractures are especially prone to shear forces, which have been shown experimentally to delay healing by disrupting callus maturation (Augat et al., 2004) [14]. The faster union observed in fractures stabilized with supplementary fixation in the present study supports earlier biomechanical and clinical evidence emphasizing the importance of controlling shear at the fracture site (Metcalfe & Saleh, 2005) [15].

Pin-track infection was the most common complication observed, though predominantly low-grade. This mirrors earlier reports indicating that pin-track infection remains the most frequent complication of circular external fixation, despite advances in pin design and care protocols (Parameswaran et al., 2003) [16]. Importantly, the association between pin-track infection and delayed union observed in this study is consistent with findings by Dahl et al. (1994) [17], who noted that persistent low-grade infection can compromise pin stability and lead to micro-motion at the bone–pin interface. The fact that pin-track infections in the present cohort preceded delayed union by several weeks highlights their potential role as an early clinical indicator of compromised healing.

An interesting observation in the present study was the relatively faster healing observed in fractures treated with minimally invasive open reduction compared to closed reduction. Although this appears counterintuitive, similar findings have been reported by Claes et al. (2002), who emphasized that improved reduction accuracy may outweigh the biological insult of limited surgical exposure. In the present study, open reduction resulted in superior reduction scores, which likely enhanced fracture stability and load sharing, thereby accelerating union. This supports the notion that achieving optimal alignment should not be sacrificed solely to preserve fracture biology, particularly when minimally invasive techniques are employed.

Functional outcomes in this study were predominantly excellent or good, aligning with reports by Tucker et al. (1992) [18], who documented favorable functional recovery following circular fixation of tibial shaft fractures. Early mobilization permitted by stable fixation likely contributed to improved joint motion and muscle function, factors known to influence overall rehabilitation outcomes. The low rates of malunion and non-union further underscore the effectiveness of controlled mechanical stability in promoting both radiological and functional success.

Overall, the findings of the present study corroborate existing evidence that fracture healing in tibial shaft fractures is influenced by a combination of biological factors, reduction quality, mechanical stability, and complication control. Circular external fixation, when applied with attention to supplementary fixation, alignment, and pin-site care, provides a reliable method for managing a wide spectrum of tibial shaft fractures with acceptable healing times and favorable functional outcomes.

Conclusion

The present study demonstrates that surgical management of displaced midshaft clavicle fractures offers clear advantages over conservative treatment in terms of both radiological and functional outcomes. Patients treated surgically achieved faster and more consistent fracture union, with a lower incidence of delayed union and non-union compared to those managed conservatively. Functional assessment using the Constant–Murley score revealed superior shoulder function in the surgical group, with a higher proportion of excellent and good outcomes and fewer residual limitations. Although conservative treatment remains a reasonable option for selected patients with lower functional demands, it was associated with delayed healing and comparatively inferior functional recovery in displaced fractures. Overall, the findings support operative fixation as a preferable treatment strategy for displaced midshaft clavicle fractures, particularly in active individuals, to ensure reliable union and optimal restoration of shoulder function.

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