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Original Research Article

Functional and Radiological Outcomes of Operative Management of Segmental Tibial Fractures: A Retrospective–Prospective Clinical Study

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Abstract

Background: Segmental tibial fractures are uncommon, high-energy injuries characterized by two or more distinct fracture lines producing an intermediate tibial segment that is completely separated from the proximal and distal fragments. The injury is clinically important because the intermediate segment may have compromised endosteal and periosteal blood supply, while associated soft-tissue damage, open injury, polytrauma and difficulties in maintaining alignment may delay healing and increase the need for secondary procedures. Contemporary literature continues to regard these fractures as a distinct and demanding subgroup of tibial shaft injuries. Objective of this study is to evaluate the radiological healing and functional outcome of surgically treated segmental tibial fractures and to describe the outcomes and complications associated with intramedullary interlocking nailing, minimally invasive plate osteosynthesis (MIPO), monolateral external fixation and Ilizarov circular fixation.

Methods: This mixed retrospective–prospective observational study included 45 patients with segmental tibial fractures treated surgically at tertiary care teaching hospital. Patients were followed for at least 12 months. Demographic characteristics, side and mechanism of injury, open/closed status, Gustilo–Anderson grade, Melis fracture type, associated injuries, treatment modality, time from injury to surgery, union of proximal and distal fracture sites, complications, secondary procedures and final functional outcome according to the Johner–Wruhs criteria were assessed. Radiological union was defined by bridging callus across at least three cortices on two views together with absence of clinical tenderness during weight bearing.

Results: The cohort comprised 39 males (86.7%) and 6 females (13.3%). The right tibia was involved in 29 patients (64.4%) and the left in 16 (35.6%). Road-traffic trauma was the mechanism in all patients. The detailed results section of the source manuscript records 26 closed and 19 open fractures; the latter included Gustilo–Anderson grade I (1), grade II (9), grade IIIA (6) and grade IIIB (3). Melis type I was most frequent (24/45, 53.3%), followed by type II (13/45, 28.9%), type III (6/45, 13.3%) and type IV (2/45, 4.4%). Intramedullary nailing was used in 32 patients (71.1%), external fixation in 6 (13.3%), MIPO in 5 (11.1%) and Ilizarov fixation in 2 (4.4%). Mean proximal and distal union times were 25.91 and 28.88 weeks after intramedullary nailing, 26.00 and 26.00 weeks after MIPO, 28.67 and 32.33 weeks after external fixation, and 31.00 and 34.00 weeks after Ilizarov fixation. The reported overall Johner–Wruhs outcome was excellent in 75.6%, good in 15.6%, fair in 6.7% and poor in 2.2%.

Conclusion: Segmental tibial fractures remain challenging injuries in which restoration of alignment, preservation of the soft-tissue envelope and protection of the intermediate segment are central to successful treatment. In this series, intramedullary nailing and MIPO were associated with comparatively shorter union times and favorable functional outcomes, while external fixation and Ilizarov fixation were mainly used in more complex open injuries. Because treatment groups were small and non-randomly allocated, the observed differences should not be interpreted as evidence of superiority of one fixation method over another.

Keywords: Segmental Tibial Fracture; Tibial Shaft Fracture; Intramedullary Nailing; Minimally Invasive Plate Osteosynthesis; External Fixation; Ilizarov Fixation; Fracture Union; Johner–Wruhs Criteria.

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Introduction

Segmental fractures of the tibial shaft represent a distinctive pattern in which two or more fracture lines create an intermediate segment that has no direct cortical continuity with the proximal and distal main fragments. In the AO/OTA system, the classic segmental pattern is included under 42-C2 injuries [7]. Unlike a simple tibial shaft fracture, the segmental pattern exposes the bone to two fracture sites, a wider zone of soft-tissue injury and a potentially vulnerable intermediate fragment. These features make reduction, maintenance of length and rotation, preservation of vascularity and predictable union more difficult.

The tibia has limited soft-tissue coverage over much of its anteromedial surface. In high-energy trauma, the periosteal and endosteal blood supply may be disrupted, while the intermediate fragment can be devascularized by the original injury or by excessive surgical exposure. This biological disadvantage is compounded by the mechanical problem of controlling two fracture levels simultaneously. Historical series therefore described segmental tibial fractures as high-risk injuries with substantial rates of delayed union, malunion, infection and reoperation [8–10].

The mechanism is commonly high-energy trauma, particularly road-traffic injury. Segmental fractures may occur in isolation but are frequently accompanied by other fractures, head injury, chest trauma, ipsilateral femoral injury or other manifestations of polytrauma. The severity of associated soft-tissue injury is particularly relevant in open fractures, for which the Gustilo–Anderson classification remains a widely used clinical framework [11,12]. Historically, treatment options have included traction and casting, plate fixation, intramedullary nailing and external fixation. Conservative treatment may be successful in carefully selected closed injuries with acceptable alignment, but maintaining reduction across two fracture sites is difficult. Intramedullary nailing has become a principal treatment option for many adult tibial shaft fractures because it provides load-sharing fixation, permits early mobilization and avoids extensive exposure of the fracture site. However, segmental fractures may require adjunctive reduction techniques because the intermediate fragment can move independently [5,9,13].

Minimally invasive plate osteosynthesis has been proposed as a biological fixation technique because indirect reduction and submuscular plate insertion can preserve periosteal circulation and reduce disruption of the fracture hematoma. External fixation remains particularly useful when soft-tissue injury makes internal fixation unsafe, while circular fixation can provide multiplanar stability and allow gradual correction of alignment or management of bone loss. The selection of a definitive method therefore depends not only on the radiographic fracture pattern but also on soft-tissue status, contamination, systemic condition, associated injuries and surgeon expertise [3,14–17].

The evidence comparing these modalities remains limited. A systematic review by McMahon and colleagues identified only 13 eligible studies and no randomized controlled trials; although intramedullary nailing appeared to have the fastest union, the heterogeneity of the available studies prevented firm conclusions regarding superiority [3]. Later observational studies have likewise emphasized the substantial burden of delayed union and complications and the importance of individualized treatment [4,5]. The present study was therefore undertaken to document the clinical, radiological and functional results of operative management in a 45-patient series.

The aim of the present study was to evaluate the functional and radiological outcomes of operative management of segmental fractures of the tibia. The study was undertaken to determine the time required for clinical and radiological union at both the proximal and distal fracture sites and to compare the pattern of fracture union among the different operative modalities used, namely intramedullary interlocking nailing, minimally invasive plate osteosynthesis (MIPO), external fixation, and Ilizarov fixation.

The study also aimed to document postoperative complications, including malalignment or angulation, delayed union, infection, pain, shortening, nonunion, muscle wasting, and soft-tissue complications. In addition, the secondary procedures required to achieve fracture healing, correct residual deformity or alignment, and control infection were recorded. Finally, the functional outcome at follow-up was assessed using the Johner–Wruhs criteria.

Materials and Methods

Study Design and Setting: The study was conducted at a tertiary care teaching hospital. It used a mixed retrospective and prospective observational design. Retrospective cases were identified from hospital records, while prospective cases were recruited through the emergency care service.

Study Population and Sample Size: Forty-five patients with surgically treated segmental tibial fractures were included. All patients were followed for a minimum of 12 months, with clinical and radiological evaluation at follow-up visits.

Inclusion Criteria: All segmental fractures of the tibia; open or closed injuries; both male and female patients; and patients presenting irrespective of duration of illness.

Exclusion Criteria: Associated vascular injury; associated neurological injury; pathological fracture; severe systemic illness such as active malignancy elsewhere in the body; and inability to provide consent.

Clinical Assessment: A detailed history and examination were performed, including general, systemic, local and neurovascular assessment. Associated injuries were documented and managed according to clinical need. The mechanism of injury, side involved, open/closed status, soft-tissue injury and associated fractures were recorded.

Radiological Assessment: Standard anteroposterior and lateral radiographs of the entire tibia, including the knee and ankle, were obtained. CT was reserved for cases in which intra-articular extension was uncertain. Acceptable alignment was described in the source manuscript as more than 50% cortical contact, less than 5–10° varus/valgus angulation, less than 10–15° anterior/posterior bowing, no more than 10–15 mm shortening and approximately 2–3° rotational discrepancy.

Fracture Classification: Segmental morphology was classified using the Melis classification. Open fractures were graded according to the Gustilo–Anderson system. The AO/OTA concept of segmental tibial fracture was also described in the source material [7,11,12].

Initial Management and Surgery: Open fractures were irrigated, debrided and temporarily immobilized using an above-knee posterior slab or calcaneal pin traction, with elevation, analgesia and antibiotics. Definitive surgery was performed after consideration of the soft-tissue condition, associated injuries and general status. The reported interval from injury to surgery ranged from 3 to 20 days.

Operative Modalities: Intramedullary interlocking nailing was the principal method. MIPO was performed using indirect reduction and submuscular insertion of a precontoured locking plate. External fixation was used primarily for open injuries requiring urgent stabilization. Ilizarov circular fixation was used in selected severe open injuries. Reduction aids included traction, manipulation, interfragmentary screws, cerclage, augmentation plating and other techniques when required.

Follow-up and Assessment: Patients were reviewed every four weeks during the first three visits and subsequently every three months for one year. At each visit, radiographs were assessed for progression of union, while clinical examination assessed tenderness, range of movement at the knee and ankle, weight-bearing status, deformity, shortening and other complaints.

Definition of Union: Clinical union was considered when tenderness at the fracture site had disappeared during weight bearing. Radiological union required bridging callus across at least three cortices on two different radiographic views. Functional outcome was graded using the Johner–Wruhs criteria [18].

Statistical Analysis: Descriptive statistics were used for categorical variables and means with standard deviations for continuous union-time measurements.

Results

A total of 45 patients with segmental tibial fractures were included and followed for a minimum of 12 months.

Table 1: Baseline demographic and injury characteristics

Parameter	Category	n	%
Sex	Male	39	86.7
	Female	6	13.3
Side	Right	29	64.4
	Left	16	35.6
Age	Range	18–65 years	—
	50–65 years	16	35.6
Mechanism	Road-traffic accident	45	100.0
Injury status	Closed	26	57.8
	Open	19	42.2
Open fracture	Gustilo I	1	2.2
	Gustilo II	9	20.0
	Gustilo IIIA	6	13.3
	Gustilo IIIB	3	6.7

The cohort was predominantly male and right-sided. Road-traffic trauma was the mechanism in all patients. The detailed Results section identified 16 patients aged 50–65 years. Open injuries represented 42.2% of the cohort, with Gustilo–Anderson grade II being the most frequent open-fracture category.

Table 2: Fracture morphology, associated injuries and initial management

Parameter	Finding	n	%
Melis classification	Type I	24	53.3
	Type II	13	28.9
	Type III	6	13.3
	Type IV	2	4.4
Associated injury	Head injury	22	48.9
	Clavicle fracture	11	24.4
	Segmental fibula fracture	11	24.4
	Distal femur + patella fracture	2	4.4
	Rib fracture	2	4.4
	Pneumothorax	1	2.2
	Metatarsal fracture	2	4.4
	Bilateral both-bone leg fracture	1	2.2
Initial immobilization	Above-knee posterior slab	26	57.8
	Calcaneal pin traction	19	42.2
Timing	Injury-to-surgery interval	3–20 days	—
Hospital stay	Reported range	7–30 days	—

Melis type I was the predominant fracture configuration. Head injury was the most frequent quantified associated injury. Initial stabilization used a posterior slab in 26 patients and calcaneal traction in 19. Definitive surgery was undertaken 3–20 days after injury according to the clinical and soft-tissue condition.

Table 3: Treatment modality and fracture union

Treatment	n	%	Proximal union, mean ± SD (weeks)	Distal union, mean ± SD (weeks)
Intramedullary interlocking nail	32	71.1	25.91 ± 5.613	28.88 ± 4.844
MIPO	5	11.1	26.00 ± 5.099	26.00 ± 3.742
External fixation	6	13.3	28.67 ± 9.092	32.33 ± 8.524
Ilizarov fixation	2	4.4	31.00 ± 7.071	34.00 ± 5.657
Overall	45	100.0	26.51	29.24

Intramedullary nailing was the dominant treatment. Proximal union occurred earlier than distal union overall. The shortest reported proximal union time was in the IMIN group, while the shortest distal union time was in the MIPO group. Because the groups were small and non-randomized, these differences are descriptive rather than evidence of treatment superiority.

Table 4: Complications, secondary procedures and statistical analysis

Domain	Finding	n / statistic	% / p value
Complication	Delayed union – IMIN	6	18.8% of IMIN
	Angulation – IMIN	8	25.0% of IMIN
	Infection – IMIN	2	6.3% of IMIN
	Angulation – external fixation	1	16.7%
	Nonunion – external fixation	1	16.7%
	Flap necrosis – external fixation	1	16.7%
Secondary procedure	Bone grafting	7	15.6% of cohort
	Dynamization	5	11.1%
	Wound debridement	4	8.9%
	Procedure conversion	3	6.7%
	Augmentation plating	2	4.4%
	Implant exit	2	4.4%
	Flap coverage	1	2.2%
	Teriparatide supplementation	1	2.2%
Statistical test	Proximal union, Kruskal–Wallis	χ^2=1.464	p=0.691
	Distal union, Kruskal–Wallis	χ^2=3.735	p=0.292

Angulation was the most frequently recorded complication in the IMIN group, followed by delayed union. Secondary procedures included dynamization, bone grafting, augmentation plating, debridement, flap coverage

and conversion of fixation. Neither proximal nor distal union time differed significantly across the treatment groups according to the reported Kruskal–Wallis analysis.

Table 5: Functional outcome according to Johner–Wruhs criteria

Treatment	n	Excellent	Good	Fair	Poor
IMIN	32	26 (81.3%)	6 (18.8%)	0	0
MIPO	5	4 (80.0%)	1 (20.0%)	0	0
External fixation	6	3 (50.0%)	1 (16.7%)	1 (16.7%)	1 (16.7%)
Ilizarov	2	0	0	2 (100.0%)	0
Overall reported result	45	75.6%	15.6%	6.7%	2.2%

The overall Johner–Wruhs result was reported as excellent in 75.6%, good in 15.6%, fair in 6.7% and poor in 2.2%. The modality-specific results were predominantly excellent or good in the IMIN and MIPO groups. External fixation had a wider outcome distribution, while both Ilizarov cases were reported as fair. These comparisons are confounded by the different severity profiles of patients receiving each fixation method.

Discussion

The present series demonstrates the characteristic clinical profile of segmental tibial fractures: a predominance of high-energy road-traffic trauma, male predominance, a substantial proportion of open injuries, frequent associated injuries and prolonged fracture healing. These observations are consistent with contemporary studies showing that segmental tibial fractures are usually associated with severe injury mechanisms and a high burden of complications [4,5,9].

The male predominance in the current cohort (86.7%) and universal association with road-traffic accidents suggest a strong relationship between the fracture pattern and high-energy trauma. Corey et al., in a 108-patient series, found that 68% of fractures were open and 31% of patients had compartment syndrome, while the median Injury Severity Score was 27 [5]. Giannoudis et al. similarly reported 19 open fractures among 27 patients and frequent associated soft-tissue problems and secondary procedures [9]. The current study's high frequency of associated head injury and other fractures supports the need for early trauma-system assessment rather than treating the tibia in isolation.

Open injury was present in approximately 42% of the current cohort, with Grade II being the most frequent open-fracture category. The absence of Grade IIIC injury reflects the study exclusion of vascular injury. The clinical significance of open injury lies in the combination of contamination, soft-tissue disruption and impaired local biology. Gustilo and Anderson, and subsequently Gustilo, Mendoza and Williams, demonstrated that increasing soft-tissue severity is associated with higher infection and healing risks [11,12]. In the current study, external fixation and Ilizarov fixation were preferentially used in open and severe injuries, which must be considered when comparing outcomes across treatment groups.

The distribution of Melis fracture types showed a predominance of type I injuries. Classification of segmental morphology is useful because the location and length of the intermediate fragment influence reduction, implant choice and biological behavior. Melis and colleagues established the clinical relevance of segmental morphology in their seminal series of 38 fractures treated with intramedullary nailing [19]. The present study similarly emphasizes that the proximal fracture line tends to unite before the distal fracture line, possibly reflecting greater soft-tissue coverage and vascularity around the proximal tibia.

Union time is a major outcome in segmental tibial fractures. In the current series, the mean union time was 26.51 weeks for the proximal fracture and 29.24 weeks for the distal fracture. This difference is clinically plausible because the distal tibia has relatively limited soft-tissue coverage. Teraa et al. reported a median union time of 34 weeks for segmental tibial fractures, significantly longer than 24 weeks in matched nonsegmental fractures. In their series, the proximal and distal fracture lines required approximately 28 and 32 weeks, respectively [8]. The pattern in the current study is therefore broadly consistent with the observation that segmental injuries heal more slowly than ordinary tibial shaft fractures.

Intramedullary nailing was the predominant fixation method in the present study. The IMIN group had mean proximal and distal union times of 25.91 and 28.88 weeks. Kakar and Tornetta reported 91% union after one operation in 51 patients followed to union after nonreamed nailing, with mean union times of 138 days for closed and 178 days for open fractures [10]. Huang et al. reported low rates of malunion, delayed union and nonunion in 33 segmental tibial fractures treated with interlocking nails [20]. These studies support the role of intramedullary fixation when soft-tissue conditions and fracture morphology permit safe nailing.

The current study documented eight cases of angulation and six cases of delayed union after

IMIN. Importantly, most alignment problems were managed without abandoning the fixation strategy: lesser angulation was treated with postoperative immobilization, while greater deformity underwent augmentation plating. Delayed union was treated using dynamization and bone grafting. These findings highlight a practical principle of segmental fracture surgery: the primary operation should be considered part of an overall treatment pathway in which timely correction of mechanical or biological problems can preserve the final result.

The MIPO group demonstrated mean proximal and distal union times of 26 weeks. Four of five patients achieved an excellent Johner–Wruhs result and one achieved a good result according to the modality-specific narrative. The rationale for MIPO is biological: indirect reduction and submuscular plate passage can minimize periosteal stripping and preserve fracture-site vascularity. Collinge and Sanders described percutaneous plating as a lower-extremity biological fixation technique [14], while Hasenboehler et al. reported clinical experience with locking compression plates using MIPO in tibial fractures [15]. Nevertheless, MIPO requires careful attention to sagittal alignment and implant positioning, and it should not be considered automatically superior to intramedullary nailing.

External fixation was used in six patients, all of whom had open injuries. This selection is clinically logical because external fixation can rapidly stabilize a severely injured limb while avoiding placement of an internal implant in an extensively contaminated or compromised soft-tissue environment. However, the external fixation group in this study had longer mean union times than the IMIN and MIPO groups and experienced nonunion, angulation, infection and soft-tissue complications. These findings are consistent with the broader literature, which reports considerable rates of malunion, nonunion and infection in segmental fractures treated with external fixation [3,9,16]. The poorer crude results should not be interpreted as a failure of external fixation because this modality was preferentially applied to the most severe open injuries.

Ilizarov fixation was used in only two patients, both with severe open segmental injuries. The small sample precludes meaningful statistical comparison. Circular external fixation offers multiplanar stability, permits postoperative correction and can be particularly useful when bone loss or soft-tissue compromise makes internal fixation inappropriate. Ozturkmen et al. reported successful union in 24 adult patients treated acutely with Ilizarov fixation [16], while Giotakis et al. reported the usefulness of circular fixation in complex segmental tibial injuries [21]. In the current series, both Ilizarov patients ultimately had fair functional outcomes, with one complicated by shortening and another by delayed union/infection and frame intolerance. The complication profile is an important finding. The most frequently documented event was angulation, particularly after IMIN, followed by delayed union. Segmental fractures are mechanically difficult because two fracture levels must be reduced and controlled simultaneously. The intermediate segment can rotate or translate during nail insertion, and proximal or distal fracture geometry may predispose to sagittal or coronal malalignment. Contemporary fixation therefore often requires poller screws, temporary plates, interfragmentary screws, reduction clamps or other adjuncts in selected cases.

The need for secondary procedures in this series is also clinically important. Dynamization, bone grafting, augmentation plating, debridement, flap coverage and conversion of the fixation construct were all required. Giannoudis et al. reported that 13 of 27 patients underwent a second operative procedure, emphasizing that segmental tibial fractures frequently require staged or secondary intervention [9]. Similarly, systematic review evidence indicates that complications and reoperation are common and that the available literature does not establish a single universally superior fixation method [3].

The functional results were generally favorable. The manuscript reports that approximately three quarters of patients achieved an excellent Johner–Wruhs result, with another 15.6% classified as good. The favorable functional outcome despite a substantial complication burden likely reflects effective management of complications rather than an absence of complications. This distinction is important: union and function may ultimately be achieved after dynamization, bone grafting, corrective plating, debridement or conversion to circular fixation.

The present findings are consistent with the conclusion of the systematic review by McMahon et al., which found that intramedullary nailing appeared to provide the fastest union but that the heterogeneity and retrospective nature of available studies prevented firm conclusions regarding superiority [3]. A later analysis of 108 patients likewise found prolonged healing, substantial delayed union and nonunion, but reported that reamed intramedullary nailing could achieve satisfactory alignment and union when used after appropriate resuscitation and stabilization [5]. A 69-patient comparison of IMN and MIPO found no significant difference in clinical and radiological outcomes according to fixation method, supporting the principle that both can be effective when soft-tissue handling and alignment are optimized [6]. An important limitation of the current analysis is the unequal distribution of patients between

treatment groups. The IMIN group contained 32 patients, compared with 5 MIPO, 6 external fixation and only 2 Ilizarov patients. In addition, treatment selection was strongly influenced by injury severity, especially open injury and soft-tissue condition. This creates confounding by indication: a fixation method used for a more severe injury may appear to have worse outcomes because the underlying injury was more severe, not because the method itself was inferior.

Another limitation is the retrospective component, which can lead to incomplete documentation and selection bias. The study was conducted at a single tertiary institution, limiting generalizability. Functional outcome was summarized categorically using Johner–Wruhs criteria, without a patient-reported validated score such as LEFS. The study also did not provide detailed patient-level data on smoking, diabetes, compartment syndrome, bone loss, fracture comminution, soft-tissue grading beyond Gustilo classification, or exact weight-bearing milestones.

Conclusion

Segmental tibial fractures are high-energy injuries characterized by complex fracture morphology, substantial soft-tissue involvement and a clinically important risk of delayed healing and complications. In this 45-patient series, road-traffic trauma was universal, males predominated, the right side was more frequently involved, and more than two-fifths of fractures were open. Melis type I was the commonest fracture configuration.

Intramedullary interlocking nailing was the most frequently used fixation method and was associated with relatively short mean union times and predominantly excellent or good functional results. MIPO also produced favorable union and functional outcomes in the small subgroup. External fixation and Ilizarov fixation were primarily reserved for severe open injuries and were associated with longer healing times and a greater need for secondary intervention, although these observations are strongly influenced by injury severity. The overall management principle is therefore not that one implant is universally superior, but that the fixation method should be selected according to fracture morphology, soft-tissue condition, contamination, associated injuries and the need to preserve the biology of the intermediate fragment. Intramedullary nailing or MIPO can be effective when adequate alignment and soft-tissue preservation are achievable, while external or circular fixation remains valuable for severe open and complex injuries. Larger multicentre prospective studies with standardized patient-reported outcomes and patient-level adjustment for injury severity are required to determine comparative effectiveness.

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