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Original Research Article

COMPARISON OF NON-UNION RATES BETWEEN HYBRID ILIZAROV FIXATION AND PLATE OSTEOSYNTHESIS IN COMMINUTED PROXIMAL TIBIAL FRACTURES

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ABSTRACT

Background: Comminuted proximal tibial fractures are difficult to manage because of articular involvement, metaphyseal comminution, and associated soft-tissue injury. Hybrid Ilizarov fixation and plate osteosynthesis are commonly used surgical options, although their comparative effects on fracture healing remain uncertain. **Objective:** To compare non-union rates and other clinical outcomes between hybrid Ilizarov fixation and plate osteosynthesis in patients with comminuted proximal tibial fractures.

Materials and Methods: This prospective comparative study included 60 patients with comminuted proximal tibial fractures treated at a tertiary-care hospital from July to December 2025. Thirty patients underwent hybrid Ilizarov fixation and 30 underwent plate osteosynthesis. The primary outcome was non-union, while secondary outcomes included time to radiological union, delayed union, infection, malunion, reoperation, and final knee flexion.

Results: Fracture union was achieved in 93.3% of patients in the hybrid Ilizarov group and 80.0% in the plate osteosynthesis group. Non-union occurred in 6.7% and 20.0%, respectively, although the difference was not statistically significant (p=0.254). Mean time to radiological union was significantly shorter with hybrid Ilizarov fixation (18.6±4.2 vs 21.7±5.1 weeks; p=0.013), while final knee flexion was greater (119.6±13.2° vs 111.8±15.4°; p=0.039). Pin-tract infection was more frequent with hybrid fixation (20.0% vs 0%; p=0.024). Deep surgical-site infection and open fractures were significantly associated with non-union.

Conclusion: Hybrid Ilizarov fixation was associated with faster fracture union and better final knee flexion, with a lower observed non-union rate than plate osteosynthesis. However, the difference in non-union was not statistically significant, and pin-tract infection was more common with hybrid fixation.

Keywords: Proximal tibial fracture; Tibial plateau fracture; Hybrid Ilizarov fixation; Plate osteosynthesis; Non-union.

INTRODUCTION

Comminuted proximal tibial and tibial plateau fractures are challenging intra-articular injuries because successful treatment requires restoration of the articular surface, mechanical axis, joint stability, and knee movement while minimizing additional damage to an already compromised soft-tissue envelope. High-energy injuries, particularly Schatzker type V and VI fractures, frequently combine bicondylar articular disruption with metaphyseal comminution, displacement, and soft-tissue injury, making definitive fixation technically demanding.[1] Contemporary management therefore emphasizes fracture morphology, soft-tissue condition, column involvement, and patient-specific factors when selecting a fixation strategy.[2]

Tibial plateau fracture epidemiology varies with age and injury mechanism. Younger patients more commonly sustain high-energy injuries, whereas

lower-energy mechanisms predominate among older individuals with reduced bone quality. Bormann et al. reported changing epidemiological patterns across a 10-year trauma-center cohort, emphasizing the heterogeneity of patients presenting with these injuries.[3] High-energy fractures are particularly relevant because they carry greater risks of soft-tissue compromise, compartment syndrome, wound complications, malalignment, and prolonged functional disability. Cross-sectional imaging is consequently important for defining fracture morphology, while magnetic resonance imaging may further characterize associated meniscal and ligamentous injuries when clinically indicated.[4]

Three-dimensional understanding of fracture morphology has also modified treatment planning. Kfuri et al. emphasized that the location and continuity of split fragments and the circumferential stability of the tibial plateau should be considered in addition to conventional Schatzker classification when selecting surgical approaches and fixation constructs.[5] Despite advances in locking plates and minimally invasive techniques, complex bicondylar fractures remain associated with substantial postoperative morbidity. A systematic review by Bullock et al. demonstrated that complex OTA/AO type-C proximal tibial injuries remain particularly susceptible to surgical-site infection, reflecting the combined influence of injury severity and soft-tissue disruption.[6]

Plate osteosynthesis provides direct or indirect reduction of the articular surface with stable internal fixation and facilitates early knee mobilization. Dual-column plating may provide strong mechanical stability in bicondylar fractures, but extensive approaches can further compromise vulnerable soft tissues. Circular or hybrid Ilizarov fixation offers an alternative based on limited internal fixation, ligamentotaxis, multiplanar stability, and reduced surgical exposure at the fracture site. Pakistani experience reported by Raza et al. has demonstrated the feasibility of primary Ilizarov fixation for complex tibial plateau fractures in a high-volume trauma setting.[7] Baloch et al. similarly reported satisfactory fracture healing and functional outcomes using the Ilizarov method, supporting its role in high-energy and soft-tissue-compromised injuries.[8]

Comparative evidence, however, has not established a universally superior technique. Tripathy et al., in a meta-analysis of 1,191 complex tibial plateau fractures, found better pooled functional scores and approximately 7.9° greater knee range of motion with external fixation, while superficial infection was more frequent with external fixation and deep infection and reoperation did not differ significantly.[9] A Pakistani randomized comparative study by Ghori et al. also found broadly comparable functional outcomes between plating and Ilizarov fixation in Schatzker V and VI fractures, although complication profiles differed between methods.[10]

The choice between plate osteosynthesis and hybrid Ilizarov fixation therefore remains particularly relevant in Pakistan, where high-energy road traffic injuries contribute substantially to the orthopedic trauma workload and patients may present with severe comminution, open wounds, or delayed referral. Local comparative evidence remains limited, and differences in injury severity, soft-tissue status, surgical resources, and follow-up may influence healing outcomes. The present study was therefore undertaken to compare non-union rates between hybrid Ilizarov fixation and plate osteosynthesis in comminuted proximal tibial fractures and to evaluate associated differences in time to union, infection, malunion, reoperation, and final knee movement.

MATERIALS AND METHODS

A prospective comparative study was conducted in the Department of Orthopaedic Surgery of a tertiary-care hospital from July to December 2025. A total of 60 patients presenting with comminuted proximal tibial fractures were enrolled through non-probability consecutive sampling. Patients were allocated into two treatment groups according to the operative management undertaken: 30 patients underwent hybrid Ilizarov fixation and 30 underwent plate osteosynthesis.

Adult patients of either sex with radiologically confirmed comminuted proximal tibial fractures, including Schatzker type V and VI fractures, who were considered suitable for operative fixation were eligible. Patients with pathological fractures, established infection at presentation, previous ipsilateral proximal tibial surgery, severe neurovascular injury requiring alternative limb-salvage procedures, or incomplete follow-up information were excluded.

Following admission, demographic characteristics, mechanism of injury, relevant comorbidities, smoking status, fracture type, open or closed injury status, and other baseline clinical characteristics were recorded using a standardized data collection form. Initial radiographs were obtained in anteroposterior and lateral projections, with computed tomography performed where required for assessment of fracture morphology and operative planning. Open fractures were managed according to institutional trauma protocols, including appropriate antimicrobial therapy and surgical debridement.

All procedures were performed by experienced orthopaedic surgical teams under standard aseptic conditions. In the hybrid Ilizarov group, fracture reduction was achieved using minimally invasive techniques where feasible, followed by stabilization using the hybrid circular external fixation construct. In the plate osteosynthesis group, reduction and fixation were achieved using an appropriate proximal tibial plate according to fracture

configuration and soft-tissue condition. Perioperative antibiotic prophylaxis, thromboprophylaxis, analgesia, wound care, and rehabilitation were provided according to institutional protocols.

Patients were followed clinically and radiographically after surgery. Fracture union was assessed using clinical stability and radiographic evidence of progressive bridging callus across the fracture site. Non-union was defined using accepted clinical and radiographic criteria, including failure of progressive fracture healing over the expected follow-up period with persistent clinical and radiological evidence of non-healing. The primary outcome was the proportion of patients developing non-union in each treatment group. Secondary outcomes included time to radiological union, delayed union, deep surgical-site infection, pin-tract infection, malunion, reoperation, and knee range of motion at final follow-up.

Data were analyzed using IBM SPSS Statistics. Continuous variables were summarized as mean ± standard deviation when approximately normally distributed, whereas categorical variables were presented as frequencies and percentages. Continuous outcomes between the two groups were compared using the independent-samples t-test, while categorical variables were compared using the chi-square test or Fisher's exact test where expected cell frequencies were small. Associations between relevant clinical factors and non-union were explored using appropriate categorical analyses. All statistical tests were two-sided, and a p-value <0.05 was considered statistically significant.

The study was conducted after approval from the institutional ethical review committee. Written informed consent was obtained from all participants before enrollment. Patient confidentiality was maintained throughout data collection, analysis, and reporting, and the study was conducted in accordance with applicable institutional ethical requirements and the principles of the Declaration of Helsinki.

RESULTS

A total of 60 patients with comminuted proximal tibial fractures were included, with 30 patients treated using hybrid Ilizarov fixation and 30 using plate osteosynthesis. The overall mean age was 42.3 ± 11.4 years, and 47 (78.3%) patients were male. Road traffic accidents were the predominant mechanism of injury, accounting for 43 (71.7%) cases. Baseline demographic and fracture characteristics were comparable between the two groups, with no statistically significant differences in age, sex, mechanism of injury, fracture classification, or diabetes mellitus (all p>0.05). Open fractures were more frequent in the hybrid Ilizarov group, although the difference did not reach statistical significance. [Table 1]

Table 1: Baseline demographic and clinical characteristics according to treatment group (n=60)

Characteristic	Hybrid Ilizarov (n=30)	Plate osteosynthesis (n=30)	p-value
Age, years, mean ± SD	41.7 ± 11.8	42.9 ± 11.2	0.688
Male sex, n (%)	24 (80.0)	23 (76.7)	0.754
Female sex, n (%)	6 (20.0)	7 (23.3)	
Road traffic accident, n (%)	22 (73.3)	21 (70.0)	0.774
Fall from height, n (%)	6 (20.0)	7 (23.3)	
Other mechanism, n (%)	2 (6.7)	2 (6.7)	
Schatzker type V, n (%)	10 (33.3)	12 (40.0)	0.592
Schatzker type VI, n (%)	20 (66.7)	18 (60.0)	
Open fracture, n (%)	11 (36.7)	6 (20.0)	0.152
Diabetes mellitus, n (%)	5 (16.7)	6 (20.0)	0.739
Current smoker, n (%)	9 (30.0)	8 (26.7)	0.774

Fracture union was achieved in 28 (93.3%) patients treated with hybrid Ilizarov fixation compared with 24 (80.0%) patients treated with plate osteosynthesis. (Figure 1) Non-union occurred in 2 (6.7%) patients in the hybrid Ilizarov group and 6 (20.0%) patients in the plate group. Although the absolute non-union rate was approximately three times higher following plate osteosynthesis, the difference did not reach conventional statistical significance (p=0.254), reflecting the limited number of non-union events. (Figure 2) The absolute risk difference was 13.3 percentage points. [Table 2]

Table 2: Comparison of fracture union and non-union between treatment groups (n=60)

Outcome	Hybrid Ilizarov (n=30)	Plate osteosynthesis (n=30)	p-value
Fracture union, n (%)	28 (93.3)	24 (80.0)	0.254
Non-union, n (%)	2 (6.7)	6 (20.0)	
Absolute difference in non-union rate	—	13.3 percentage points higher	—
Relative risk of non-union, plate vs Ilizarov	Reference	3.00	—

The mean time to radiological union was shorter in the hybrid Ilizarov group than in the plate osteosynthesis group (18.6 ± 4.2 vs 21.7 ± 5.1 weeks; p=0.013). Delayed union was also less frequent following hybrid Ilizarov fixation (13.3% vs 30.0%), although this difference was not

statistically significant. Deep surgical-site infection occurred in 2 (6.7%) patients in the hybrid Ilizarov group compared with 5 (16.7%) patients in the plate group. In contrast, pin-tract infection was observed exclusively among patients treated with hybrid Ilizarov fixation and was generally managed conservatively. Reoperation was required in 2 (6.7%) and 6 (20.0%) patients, respectively. [Table 3]

Table 3: Comparison of fracture-healing and postoperative outcomes

Outcome	Hybrid Ilizarov (n=30)	Plate osteosynthesis (n=30)	p-value
Time to radiological union, weeks, mean ± SD	18.6 ± 4.2	21.7 ± 5.1	0.013
Delayed union, n (%)	4 (13.3)	9 (30.0)	0.117
Deep surgical-site infection, n (%)	2 (6.7)	5 (16.7)	0.424
Pin-tract infection, n (%)	6 (20.0)	0 (0.0)	0.024
Malunion, n (%)	2 (6.7)	4 (13.3)	0.671
Reoperation, n (%)	2 (6.7)	6 (20.0)	0.254
Knee flexion at final follow-up, degrees, mean ± SD	119.6 ± 13.2	111.8 ± 15.4	0.039

Exploratory analysis showed that non-union was more frequent among patients with open fractures, Schatzker type VI fractures, diabetes mellitus, smoking history, and deep surgical-site infection. The strongest association was observed with deep infection, with non-union occurring in 4 of 7 (57.1%) patients with deep infection compared with 4 of 53 (7.5%) without deep infection (p=0.003). Open fractures were also significantly associated with non-union (29.4% vs 7.0%; p=0.032). [Table 4]

Table 4: Factors associated with non-union in the overall study population (n=60)

Factor	Non-union present	Union achieved	p-value
Open fracture	5/17 (29.4%)	12/17 (70.6%)	0.032
Closed fracture	3/43 (7.0%)	40/43 (93.0%)	
Schatzker type VI	6/38 (15.8%)	32/38 (84.2%)	0.456
Schatzker type V	2/22 (9.1%)	20/22 (90.9%)	
Diabetes mellitus	3/11 (27.3%)	8/11 (72.7%)	0.130
No diabetes mellitus	5/49 (10.2%)	44/49 (89.8%)	
Current smoker	4/17 (23.5%)	13/17 (76.5%)	0.196
Non-smoker	4/43 (9.3%)	39/43 (90.7%)	
Deep surgical-site infection	4/7 (57.1%)	3/7 (42.9%)	0.003
No deep infection	4/53 (7.5%)	49/53 (92.5%)	

Overall, hybrid Ilizarov fixation demonstrated a lower observed non-union rate and a significantly shorter mean time to radiological union than plate osteosynthesis. The between-group difference in non-union itself was not statistically significant, and therefore the findings support a potentially favorable healing profile with hybrid Ilizarov fixation rather than definitive superiority for the primary outcome.

Figure 1A: Postoperative lateral radiograph of the right proximal tibia showing fixation of a comminuted fracture with a hybrid Ilizarov external fixator and plate osteosynthesis

Figure 1B: Postoperative clinical photograph showing hybrid Ilizarov external fixation of a comminuted proximal tibial fracture during assisted weight-bearing

Figure 2A: Preoperative anteroposterior and lateral radiographs of the right knee showing a comminuted proximal tibial plateau fracture with articular surface involvement and metaphyseal extension

Figure 2B: Postoperative anteroposterior and lateral radiographs showing reduction and internal fixation of the proximal tibial plateau fracture with plate-and-screw osteosynthesis

DISCUSSION

The present study demonstrated a clinically meaningful difference in fracture healing between the two fixation strategies. Non-union occurred in 6.7% of patients treated with hybrid Ilizarov fixation compared with 20.0% following plate osteosynthesis, corresponding to a relative risk of 3.0 for plating. However, the difference did not reach statistical significance (p=0.254), probably because only eight non-union events occurred in the 60-patient cohort. Thus, the findings suggest a favorable healing profile with hybrid fixation rather than definitive evidence of superiority. A recent Pakistani study by Ali et al. reported a contrasting pattern, with radiological union in 73.3% of Ilizarov-treated patients and 96.7% of dual-plating patients (p=0.01), illustrating that outcomes may depend considerably on patient selection, fracture characteristics, fixation technique, and local expertise.[11]

Oguzkaya et al. compared double-plate fixation with Ilizarov fixation in Schatzker V and VI fractures and found both techniques capable of achieving acceptable clinical and radiological results, reinforcing the concept that treatment selection should be individualized rather than based on a single universally superior construct.[12] Subash et al., in a prospective series of Schatzker V and VI fractures managed with hybrid external fixation, also reported satisfactory fracture healing and functional recovery, supporting hybrid fixation as a viable strategy for complex proximal tibial injuries.[13]

A notable finding in our study was the shorter time to radiological union with hybrid Ilizarov fixation, averaging 18.6 ± 4.2 weeks compared with 21.7 ± 5.1 weeks after plating (p=0.013). Kumar et al. reported an average union time of 17.4 weeks among patients with bicondylar fractures treated using dual locking plates, demonstrating that satisfactory union can also be achieved with modern internal fixation when soft-tissue management and fixation stability are optimized.[14] Raj et al. likewise reported favorable clinical and radiological outcomes following dual plating of unstable bicondylar fractures, suggesting that meticulous reduction and stable fixation remain central determinants of healing irrespective of implant category.[15]

The difference in knee movement also favored hybrid fixation. Mean final flexion was 119.6° after hybrid Ilizarov fixation and 111.8° following plate osteosynthesis (p=0.039). This finding is consistent with evidence that stable circular fixation can permit early joint mobilization while minimizing additional disruption of the periarticular soft tissues. Vasiliadis et al. reported satisfactory mid-term function after dual-plate fixation, showing that good movement is also achievable after internal fixation when rehabilitation is appropriately implemented.[16]

Deep surgical-site infection occurred in 6.7% of the Ilizarov group and 16.7% of the plate group, although the difference was not significant. Guild et al. reported deep infection rates exceeding 20% among some dual-plated bicondylar fracture cohorts, emphasizing the vulnerability of these high-energy injuries to wound complications.[17] Coelho et al. found an overall postoperative infection rate of 11.3% and identified open fractures and Schatzker V–VI patterns as significant infection-related factors.[18] In our cohort, deep infection was strongly associated with non-union, which occurred in 57.1% of patients with deep infection compared with 7.5% without infection (p=0.003), supporting the biological importance of infection in impaired fracture healing.

The principal complication specific to hybrid fixation was pin-tract infection, occurring in 20.0% versus none after plating (p=0.024). Stefanelli et al. similarly documented infection, stiffness, malunion, and secondary procedures among patients managed with minimally invasive screws or hybrid external fixation, with complication burden increasing in bicondylar fractures.[19] Berto et al. nevertheless showed satisfactory consolidation and functional results using circular external fixation, suggesting that frame-related morbidity can often be managed without compromising final fracture healing.[20]

Open fractures were another significant determinant of non-union in our study, with rates of 29.4% in open fractures and 7.0% in closed injuries (p=0.032). This likely reflects greater periosteal disruption, contamination, vascular compromise, and soft-tissue damage. Contemporary fixation research continues to emphasize preservation of the biological environment surrounding complex bicondylar fractures; Wang et al. showed that strategies providing mechanical stability while limiting unnecessary soft-tissue disruption can produce favorable results.[21] Staged treatment principles are also widely employed in high-energy bicondylar injuries to permit soft-tissue recovery before definitive internal fixation.[22]

Overall, the present findings suggest that hybrid Ilizarov fixation may offer advantages in time to union, knee flexion, and potentially non-union and deep-infection rates, at the expense of pin-tract infection. Because the primary difference in non-union did not reach statistical significance and the study included only 30 patients per group, larger prospective multicenter studies with adjustment for open fracture status, smoking, diabetes, fracture severity, and infection are required before definitive superiority can be established.

CONCLUSION

Hybrid Ilizarov fixation demonstrated faster radiological union and better final knee flexion, with a lower observed rate of non-union compared with plate osteosynthesis. However, the difference in non-union was not statistically significant, while pin-tract infection remained an important complication of hybrid fixation.

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