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KEY WORDS: distal tibial fracture; minimally invasive plate osteosynthesis; external fixation; open reduction internal fixation; AOFAS score

RADIOLOGICAL, CLINICAL AND FUNCTIONAL OUTCOMES OF INTRAARTICULAR DISTAL TIBIA FRACTURE TREATED WITH VARIOUS SURGICAL MODALITIES

Dr. Saurya Shivam* Department of Orthopaedics, Index Medical College Hospital and Research Centre, Indore (M.P.)*Corresponding Author

Dr. Lavesh Agrawal Professor, Department of Orthopaedics, Index Medical College Hospital and Research Centre, Indore (M.P.)

Dr. Vinay Dubey Department of Orthopaedics, Index Medical College Hospital and Research Centre, Indore (M.P.)

Dr. Rohit Yadav Department of Orthopaedics, Index Medical College Hospital and Research Centre, Indore (M.P.)

ABSTRACT

Background: Intra-articular distal tibial fractures are complex injuries associated with limited soft tissue coverage, compromised vascularity, and a high risk of postoperative complications. Various surgical techniques have been advocated; however, the optimal treatment modality remains controversial. **Methods:** This prospective comparative cohort study was conducted at Index Medical College Hospital and Research Centre, Indore, between May 2024 and November 2025. Forty patients aged 18–65 years with intra-articular distal tibial fractures were included. Based on fracture morphology and soft tissue condition, patients underwent minimally invasive plate osteosynthesis (MIPO; n=21), open reduction and internal fixation with plating (ORIF-P; n=10), or external fixation (EF; n=9). Clinical, radiological, and functional outcomes were evaluated over a minimum follow-up of 12 months. Functional outcome was assessed using the American Orthopaedic Foot and Ankle Society (AOFAS) score, while radiological assessment included residual varus and valgus deformity. Postoperative complications were also recorded. **Results:** The mean patient age was 42.0 ± 14.52 years, and 80% were male. MIPO achieved significantly superior functional outcomes, with a mean AOFAS score of 87.71 ± 7.32, compared with 75.20 ± 7.80 in the ORIF-P group and 71.11 ± 5.62 in the EF group ($p < 0.001$). Residual varus and valgus deformities were significantly lower in the MIPO group ($p < 0.001$ and $p = 0.003$, respectively). Overall, 75% of patients experienced no postoperative complications. The EF group demonstrated the highest complication rate, whereas 81% of patients treated with MIPO had an uncomplicated postoperative course ($p = 0.046$). **Conclusions:** MIPO demonstrated superior functional recovery, better restoration of anatomical alignment, and fewer postoperative complications compared with ORIF-P and external fixation. Preservation of fracture biology and soft tissue integrity makes MIPO the preferred surgical technique for appropriately selected patients with intra-articular distal tibial fractures.

INTRODUCTION

Fractures are among the most common non-fatal consequences of road traffic accidents, with the lower extremities being particularly vulnerable to injury. The tibia is the most frequently fractured long bone, and fractures involving the distal third represent the second most common type of tibial fracture after shaft fractures [1]. Distal tibial fractures usually result from high-energy trauma, such as road traffic accidents or falls from height, and are frequently associated with severe soft tissue injury, comminution, and intra-articular extension. The unique anatomical characteristics of the distal tibia, including limited soft tissue coverage and relatively poor vascularity, make these fractures particularly difficult to manage. Successful treatment requires restoration of the articular surface, maintenance of fracture alignment, and preservation of the surrounding soft tissues to promote optimal healing.

Despite advances in surgical management, complications such as delayed union, non-union, malunion, wound dehiscence, infection, and post-traumatic osteoarthritis continue to pose significant challenges. Careful soft tissue handling, anatomical reduction of the articular surface, stable fixation, and early mobilization of the ankle joint are essential for achieving favorable radiological and functional outcomes [2].

The management of distal tibial fractures has evolved considerably over the past several decades. The landmark study by Rüedi and Allgöwer in 1962 revolutionized treatment by demonstrating that 74% of patients achieved good functional outcomes after four years following anatomical reduction and stable internal fixation [3]. Subsequently, open reduction and internal fixation (ORIF) became the standard treatment during the 1970s and 1980s. However, extensive surgical exposure was associated with high rates of complications, including superficial and deep infections, osteomyelitis, non-union, malunion, arthrodesis, post-traumatic osteoarthritis, and even transtibial amputation [3,4]. In later follow-up studies, Rüedi and Allgöwer reported improved long-term outcomes predominantly in patients with low-energy injuries, highlighting the importance of soft tissue preservation in successful fracture management [5,6]. They further demonstrated that fractures caused by low-velocity trauma had better outcomes than those resulting from high-energy mechanisms, emphasizing the need for meticulous soft tissue management alongside fracture stabilization [7,8].

Several surgical techniques are currently available for treating intra-articular distal tibial fractures, including open reduction and internal fixation, minimally invasive plate osteosynthesis (MIPO), intramedullary nailing, ankle-spanning external fixation, and circular ring fixators. The ideal treatment should provide stable fixation, maintain anatomical reduction, preserve fracture biology, and facilitate early rehabilitation. Therefore, the present study aims to evaluate and compare the radiological, clinical, and functional out-comes of intraarticular distal tibial fractures managed with different surgical techniques, thereby identifying the most appropriate surgical approach for individualized patient care.

MATERIAL AND METHODS

This prospective comparative cohort study was conducted in the Department of Orthopaedics at Index Medical College Hospital and Research Centre, Indore, after obtaining approval from the Institutional Ethics Committee (Approval No. IMCHRC/IEC/2024/83; April 20, 2024). The study was carried out between May 2024 and November 2025. Written informed consent was obtained from all participants before enrolment.

A total of 40 patients aged 18–65 years with intra articular distal tibial fractures were included in the study. Patients were managed using different surgical techniques based on fracture morphology, degree of articular involvement, and soft tissue condition. Clinical, radiological, and functional outcomes were prospectively evaluated over a minimum follow-up period of 12 months.

Inclusion and Exclusion Criteria

The inclusion criteria comprised patients aged 18–65 years with radiologically confirmed intra-articular distal tibial fractures. Both open and closed fractures were included.

Patients presenting with associated neurovascular injuries, previous fractures involving the ipsilateral knee, ankle, or foot, pre-existing deformities of the affected limb, pathological fractures, or refusal to provide informed consent were excluded from the study.

METHODOLOGY

Clinical Evaluation and Surgical Management

All patients underwent a detailed clinical assessment at admission, including history taking, general physical examination, and local examination. Following initial stabilization, radiological evaluation was performed using standard anteroposterior, lateral, and oblique radiographs of the affected leg, with computed tomography (CT) scans obtained when required to assess fracture configuration and intra-articular extension. Fractures were classified according to the AO/OTA classification system, while open fractures were graded using the Gustilo-Anderson classification.

The choice of surgical procedure was individualized according to fracture morphology, fracture pattern, degree of comminution, and soft tissue status. Surgical modalities included open reduction and internal fixation (ORIF), minimally invasive plate osteosynthesis (MIPO), intramedullary nailing, external fixation, or hybrid fixation as appropriate. All procedures were performed under fluoroscopic (C-arm) guidance to achieve anatomical reduction and stable fixation.

Postoperatively, intravenous antibiotics were administered until the fifth postoperative day, followed by oral antibiotics until suture removal. Patients were encouraged to begin ankle range-of-motion exercises and non-weight-bearing ambulation with walker support as permitted by fixation stability. Sutures were removed on the 12th postoperative day.

Radiological and Functional Assessment

Postoperative radiographs were obtained immediately after surgery and during follow-up to assess fracture alignment, maintenance of reduction, and progression of fracture union. Standard anteroposterior and lateral radiographs of the tibia, including the knee and ankle joints, were evaluated.

Coronal plane alignment was assessed by measuring varus or valgus angulation, whereas sagittal plane alignment was assessed by measuring procurvatum or recurvatum angulation. Malalignment was defined as angulation greater than 5° in either plane. Fracture union was assessed clinically by the absence of pain and tenderness at the fracture site during weight-bearing and radiologically by the presence of bridging callus across at least three cortices.

Patients were followed at 2, 4, 8, and 12 weeks postoperatively, followed by monthly visits until six months, with a final assessment at 12 months. At each visit, clinical examination included wound healing, ankle range of motion, weight-bearing status, and assessment for complications such as superficial or deep infection, wound dehiscence, delayed union, non-union, malunion, and ankle stiffness. Functional outcome was evaluated using the American Orthopaedic Foot and Ankle Society (AOFAS) Ankle-Hindfoot Score, which assesses pain, function, and alignment, with a maximum score of 100 points.

Outcome Measures

The primary outcome measures were radiological union, maintenance of fracture alignment, and functional outcome as assessed by the AOFAS Ankle-Hindfoot Score. Secondary outcome measures included time to fracture union, ankle range of motion, progression to weight-bearing, and the incidence of complications including infection, wound dehiscence, malunion, non-union, delayed union, and ankle stiffness.

Statistical Analysis

Data were entered into Microsoft Excel and analyzed using IBM Statistical Package for the Social Sciences (SPSS) Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation or median with interquartile range, depending on data distribution. Categorical variables were expressed as frequencies and percentages. Continuous variables were compared using the independent Student's *t*-test or Mann-Whitney *U* test, while categorical variables were analyzed using the chi-square test or Fisher's exact test, as appropriate. A *p*-value of <0.05 was considered statistically significant.

RESULTS

A total of 40 patients with intra-articular distal tibial fractures were included in this prospective comparative cohort study. Based on fracture configuration and soft tissue status, 21 patients (52.5%) underwent minimally invasive plate osteosynthesis (MIPO), 10 patients (25.0%) underwent open reduction and internal fixation with plating (ORIF-P), and 9 patients (22.5%) were managed with external fixation (EF).

Baseline Characteristics: The mean age of the study population was 42.0 ± 14.52 years (range: 18-64 years). The majority of patients belonged to the 18-30 years age group (27.5%), followed by the 51-60 years age group (22.5%). Age distribution differed significantly among the treatment groups ($p = 0.001$). Most patients in the MIPO group were aged 51-60 years (42.9%), whereas ORIF-P was predominantly performed in patients aged 31-40 years (60.0%). External fixation was more commonly used in younger patients, with 55.6% belonging to the 18-30 years age group.

Overall, 32 patients (80.0%) were males and 8 (20.0%) were females. Male predominance was observed in all treatment groups, although the difference was not statistically significant ($p = 0.092$).

The right lower limb was involved in 30 patients (75.0%), while the left side was affected in 10 patients (25.0%). Right-sided injuries were significantly more frequent in the MIPO and EF groups, whereas left-sided injuries predominated in the ORIF-P group ($p = 0.013$).

Table 1. Baseline Demographic and Clinical Characteristics According to Treatment Modality

Variable	MIPO (n=21)	ORIF-P (n=10)	EF (n=9)	Total (N=40)	p-value
Treatment modality, n (%)	21 (52.5)	10 (25.0)	9 (22.5)	40 (100)	—
Age group, n (%)	0.001*				
18-30 years	4 (19.0)	2 (20.0)	5 (55.6)	11 (27.5)	
31-40 years	0 (0.0)	6 (60.0)	2 (22.2)	8 (20.0)	
41-50 years	5 (23.8)	2 (20.0)	0 (0.0)	7 (17.5)	
51-60 years	9 (42.9)	0 (0.0)	0 (0.0)	9 (22.5)	
61-64 years	3 (14.3)	0 (0.0)	2 (22.2)	5 (12.5)	
Gender, n (%)	0.092				
Male	17 (81.0)	6 (60.0)	9 (100.)	32 (80.0)	
Female	4 (19.0)	4 (40.0)	0 (0.0)	8 (20.0)	
Side involved, n (%)	0.013*				
Right	18 (85.7)	4 (40.0)	8 (88.9)	30 (75.0)	
Left	3 (14.3)	6 (60.0)	1 (11.1)	10 (25.0)	

Chi-square test; p <0.05 considered statistically significant.

Functional and Radiological Outcomes: At the final follow-up, the MIPO group demonstrated the highest functional outcome, with a mean AOFAS score of 87.71 ± 7.32, followed by the ORIF-P group (75.20 ± 7.80) and the EF group (71.11 ± 5.62). The difference among the three groups was highly statistically significant ($p < 0.001$).

Residual deformity was also significantly lower in patients treated with MIPO. The mean varus angle was 3.16 ± 0.75° in the MIPO group compared with 6.50 ± 0.71° in the ORIF-P group and 8.00° in the EF group ($p < 0.001$). Similarly, the mean valgus angle was significantly lower in the MIPO group (3.13 ± 1.55°) than in the ORIF-P (4.50 ± 2.14°) and EF (6.25 ± 2.25°) groups ($p = 0.003$).

Table 2. Comparison of Functional and Radiological Outcomes among Treatment Groups

Outcome	MIPO (n=21)	ORIF-P (n=10)	EF (n=9)	p-value
AOFAS score (Mean ± SD)	87.71 ± 7.32	75.20 ± 7.80	71.11 ± 5.62	<0.001 *
Varus angle (°), Mean ± SD	3.16 ± 0.75	6.50 ± 0.71	8.00	<0.001 *
Valgus angle (°), Mean ± SD	3.13 ± 1.55	4.50 ± 2.14	6.25 ± 2.25	0.003*

One-way ANOVA; p <0.05 considered statistically significant.

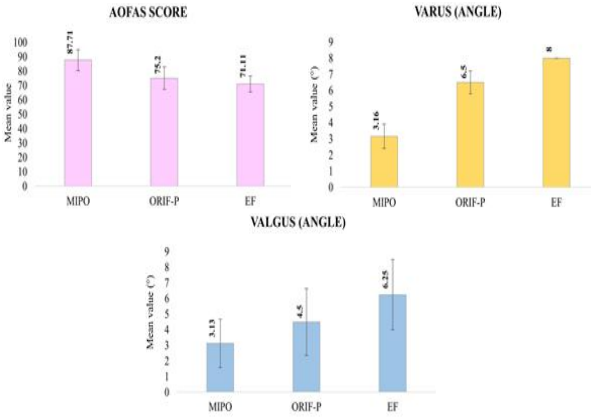

Figure 1. Comparison of Functional and Radiological Outcomes among Treatment Groups

Post hoc analysis demonstrated that the MIPO group had significantly better AOFAS scores than both the ORIF-P (mean difference = 12.51, $p < 0.001$) and EF groups (mean difference = 16.60, $p < 0.001$). No significant difference was observed between the ORIF-P and EF groups ($p = 0.432$).

For valgus angle, the difference between MIPO and EF was statistically significant (mean difference = -3.11°, $p = 0.002$), whereas comparisons between MIPO and ORIF-P ($p = 0.245$) and between ORIF-P and EF ($p = 0.175$) were not significant.

Table 3. Post hoc pairwise comparison of treatment groups

Outcome	Comparison	Mean Difference	p-value
AOFAS score	MIPO vs ORIF-P	12.51	<0.001*
	MIPO vs EF	16.60	<0.001*
	ORIF-P vs EF	4.08	0.432
Valgus angle	MIPO vs ORIF-P	-1.36	0.245
	MIPO vs EF	-3.11	0.002*
	ORIF-P vs EF	-1.75	0.175

Tukey's post hoc test; p <0.05 considered statistically significant.

Deformity Pattern and Postoperative Complications: Valgus deformity was observed more frequently than varus deformity, occurring in 31 patients (77.5%), whereas 9 patients (22.5%) developed varus deformity. The distribution of deformity patterns was comparable among the treatment groups and did not reach statistical significance ($p = 0.563$).

Overall, 30 patients (75.0%) experienced no postoperative complications. The most common complication was ankle stiffness (15.0%), followed by combined wound discharge with ankle stiffness (5.0%). Non-union and isolated wound discharge each occurred in 2.5% of patients.

The MIPO and ORIF-P groups demonstrated favorable safety profiles, with 81.0% and 90.0% of patients, respectively, remaining free of complications. In contrast, complications were more frequent in the EF group, where only 44.4% of patients experienced an uncomplicated postoperative course. The overall complication rate differed significantly among treatment groups ($p = 0.046$).

Table 4. Deformity Pattern and Postoperative Complications According to Treatment Modality

Variable	MIPO (n=21)	ORIF-P (n=10)	EF (n=9)	Total (N=40)	p-value
Deformity pattern	0.563				
Varus	6 (28.6)	2 (20.0)	1 (11.1)	9 (22.5)	
Valgus	15 (71.4)	8 (80.0)	8 (88.9)	31 (77.5)	
Postoperative complications	0.046*				
None	17 (81.0)	9 (90.0)	4 (44.4)	30 (75.0)	
Ankle stiffness	4 (19.0)	1 (10.0)	1 (11.1)	6 (15.0)	
Wound discharge	0	0	1 (11.1)	1 (2.5)	
Non-union	0	0	1 (11.1)	1 (2.5)	
Wound discharge with ankle stiffness	0	0	2 (22.2)	2 (5.0)	

Chi-square test; p <0.05 considered statistically significant.

Overall, patients treated with MIPO achieved significantly superior functional outcomes, lower residual deformity angles, and fewer postoperative complications than those managed with ORIF-P or EF. External fixation demonstrated the highest complication rate and the least favorable clinical and radiological outcomes. These findings suggest that MIPO provides the most favorable overall outcome for the surgical management of intra-articular distal tibial fractures in appropriately selected patients.

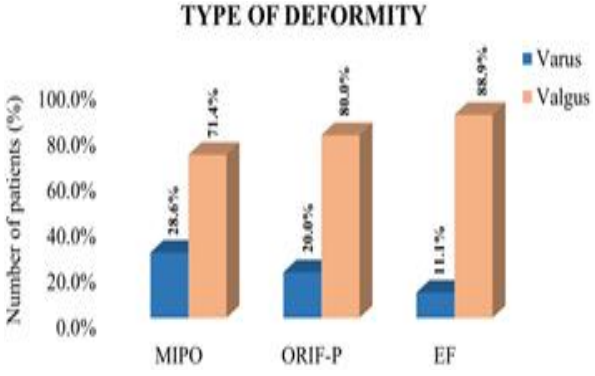

Figure 2. Distribution of Patients Based nn type of Deformity

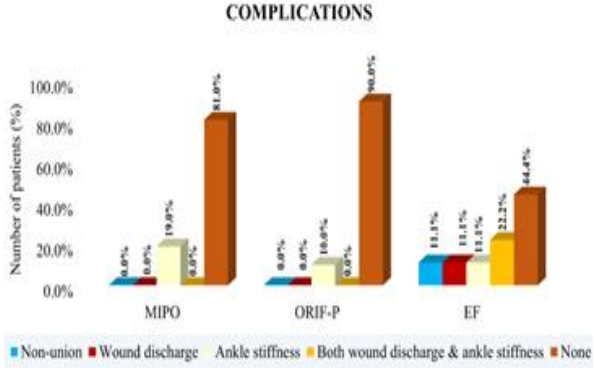

Figure 3. Distribution of Patients based on complications.

Figure 4. Representative Clinical Cases Treated with External Fixation, Minimally Invasive Plate Osteosynthesis (MIPO), and Open Reduction Internal Fixation with Plating (ORIF-P)

Figure 5: Case Of Distal Tibial Intraarticular Fracture Trea-tedWith External Fixator

DISCUSSION

Distal tibial fractures remain among the most challenging injuries in orthopaedic trauma because of the limited soft tissue envelope, compromised vascularity, and the need to achieve stable fixation while preserving fracture biology. In the present study, minimally invasive plate osteosynthesis (MIPO), open reduction and internal fixation with plating (ORIF-P), and external fixation (EF) were compared. The findings demonstrated that MIPO provided significantly better functional outcomes, superior alignment, and fewer postoperative complications than ORIF-P and EF.

The mean age of the study population was 42.0 ± 14.52 years, with 80% of patients being male. These findings are consistent with those of Zelle et al., who reported that distal tibial fractures predominantly occur in young and middle-aged men following high-energy trauma such as road traffic accidents and falls from height [9]. Younger patients in the present study were more frequently managed with external fixation ($p = 0.001$), reflecting the greater severity of soft tissue injury in high-energy fractures where staged fixation is often required [9].

Functional outcome assessed using the American Orthopaedic Foot and Ankle Society (AOFAS) score was significantly better in the MIPO group (87.71 ± 7.32) than in the ORIF-P (75.20 ± 7.80) and EF (71.11 ± 5.62) groups ($p < 0.001$). These findings are in agreement with Paluvadi et al., who reported superior functional recovery following MIPO due to preservation of periosteal blood supply and minimal soft tissue disruption [10]. Similarly, Cheng et al. demonstrated in a meta-analysis that MIPO is associated with earlier functional recovery and lower complication rates than conventional open plating techniques [11]. These observations support the biological advantages of minimally invasive fixation in distal tibial fractures.

Restoration and maintenance of anatomical alignment are essential for achieving favorable long-term outcomes following intra-articular distal tibial fractures, as residual malalignment predisposes patients to post-traumatic arthritis and impaired function. In the present study, patients treated with MIPO demonstrated significantly lower residual deformity than those managed with ORIF-P or EF. The mean residual varus angle was 3.16° in the MIPO group compared with 6.50° in the ORIF-P group and 8.00° in the EF group ($p < 0.001$). Similarly, the mean valgus angle was significantly lower following MIPO (3.13°) than ORIF-P (4.50°) and EF (6.25°, $p = 0.003$). These findings are consistent with Abbas et al., who described MIPO as a biological fixation technique capable of restoring excellent coronal and sagittal alignment while preserving vascularity and promoting fracture healing [12]. Likewise, Gupta et al. reported that although external fixation provides satisfactory initial stability, it is less effective than minimally invasive locking plate fixation in maintaining anatomical reduction during fracture healing [13].

Although valgus deformity was more common than varus deformity in the present study (77.5% vs. 22.5%), the distribution of deformity patterns did not differ significantly among treatment groups ($p = 0.563$). However, the significantly lower residual deformity angles observed following MIPO indicate superior maintenance of fracture reduction, which may contribute to improved long-term ankle function and a lower risk of post-traumatic osteoarthritis.

Postoperative complications were significantly associated with the choice of surgical technique ($p = 0.046$). Overall, 75% of patients had an uncomplicated postoperative course, while 81% of patients treated with MIPO experienced no complications. In contrast, the EF group demonstrated the highest complication rate, including non-union, wound discharge, and ankle stiffness. These findings are comparable to those reported by Pollak et al., who identified pin-tract infection, malunion, and delayed union as common complications of external fixation [14]. Similarly, Lau et al. demonstrated that MIPO reduces wound-related complications by minimizing soft tissue dissection and preserving the periosteal blood supply, thereby decreasing the incidence of infection and wound healing problems [15]. The lower complication rate observed with MIPO in the present study further supports its role as a safe and effective treatment option for intra-articular distal tibial fractures.

The findings of the present study demonstrate that MIPO combines the biological advantages of minimally invasive surgery with the mechanical stability of locked plate fixation, resulting in better functional recovery, improved maintenance of anatomical alignment, and fewer postoperative complications than ORIF-P and external fixation. By preserving the periosteal blood supply and minimizing soft tissue disruption, MIPO promotes fracture healing while facilitating early rehabilitation. Although external fixation remains an important option for high-energy fractures with severe soft tissue injury, its long-term functional and radiological outcomes were comparatively inferior.

The present study has certain limitations. The relatively small sample size (40 patients), non-randomized treatment allocation, and single-centre design may limit the generaliz-ability of the findings. Additionally, the one-year follow-up period was insufficient to assess long-term outcomes such as posttraumatic

osteoarthritis and implant-related compli-cations.

Overall, the present study supports the growing evidence that minimally invasive plate osteosynthesis provides superior functional outcomes, better anatomical alignment, and lower complication rates than ORIF-P and external fixation in the management of intra-articular distal tibial fractures [10–15].

CONCLUSION

Intra-articular distal tibial fractures require treatment that balances stable fixation with preservation of the biological environment for fracture healing. In the present study, minimally invasive plate osteosynthesis (MIPO) demonstrated superior functional outcomes, better restoration and maintenance of anatomical alignment, and lower complication rates compared with open reduction and internal fixation with plating (ORIF-P) and external fixation (EF). Preservation of the soft tissue envelope and periosteal blood supply likely contributed to these favorable results. Although external fixation remains valuable for high-energy fractures with compromised soft tissues, it was associated with higher complication rates and poorer functional recovery. Therefore, MIPO should be considered the preferred surgical technique in appropriately selected patients.

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