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Functional Recovery and Complication Patterns After Surgical Treatment of Pilon Fractures

(A 12-Month Prospective Study)

Abstract

Introduction: Intra-articular pilon fractures of the distal tibia are complicated fractures with far-reaching long-term functional consequences. Despite improved surgical methods, the ideal management protocols and resulting recuperation patterns continue to be topics of recent investigation. This study aims to compare functional outcome, and rates of complications after surgical management of pilon fractures by open reduction and internal fixation (ORIF) or minimally invasive plate osteosynthesis (MIPO) and also to compare the effect of age on recovery and modes of complications.

Materials & Methods: This is a prospective observational cohort study of 183 type B or C pilon fracture patients treated at a single trauma center. The level of functional recovery 2 weeks, 6 weeks, 3 months, 6 months, and 12 months post-injury was measured by the Foot Function Index (FFI). Postoperative complications were noted, and the time to return to normal activities. Repeated-measures ANOVA was employed in the assessment of temporal changes in FFI scores.

Results & Discussion: There was significant improvement on all subscales of FFI during 12 months of time ($P<0.001$), with most improvement in the first 6 months. The mean duration of time to return to activity was 25.5±7.5 weeks. Complications were malunion (23.0%), nonunion (30.6%), deep infection (15.8%), loosening of implant (14.8%), and reoperation (36.6%). Age was correlated with increased complications. Compared with ORIF, MIPO achieved comparable 12-month functional recovery (FFI improvement) while demonstrating a lower, though not statistically significant, rate of deep infection, suggesting similar efficacy with a potential advantage in soft-tissue preservation.

Conclusion: Operative management of pilon fracture yields significant functional improvement, although complications are common. Prognosis depends on age. Preoperative planning should be meticulous, close observation necessary, and individualized rehabilitation in order to maximize outcome.

Keywords: Tibial fractures, Treatment outcomes, Fracture healing

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Introduction

Pilon fractures are complex intra-articular fractures involving the distal tibia, often extending into the weight-bearing surface of the ankle joint.[1] While pilon fractures are less than 10% of tibial fractures, they have exceedingly high morbidity, enormous rehabilitation, and substantial socioeconomic expense due to prolonged disability and lost productivity.[2] They typically result from high-energy trauma mechanisms, including motor vehicle collisions, falls from considerable heights, and high-impact sports injuries. The complexity of pilon fractures is largely attributed to the comminuted nature of the fracture and the concomitant soft tissue injury, which often involves muscles, ligaments, neurovascular structures, and the overlying skin.[3] These fractures commonly affect the articular surface, metaphysis, and sometimes diaphysis of the tibia and are accompanied by a combination of axial compression, torsional force, and shearing injuries. The resultant joint incongruity and limb deformity present a significant challenge during surgical planning.[4]

Optimal pilon fracture management needs advanced surgical skills to achieve precise anatomical reduction and stable fixation, which are essential in restoring function and minimizing long-term sequelae such as post-traumatic arthritis.[1, 5] Historically, these

fractures have had high complication rates with attention mainly centered around infection, nonunion, and malunion, largely due to the severity of the original injury and technical requirements of the surgical fixation. Other complications of deep infection, implant failure, wound dehiscence, and post-traumatic arthritis occur often and can significantly reduce long-term function. Notably, reoperation rates remain relatively high in some series, especially with complex fracture patterns like the C3-type.[6-8] Definitive timing of surgical repair has also been a point of concern; delayed fixation techniques are being employed most commonly to facilitate resolution of soft tissue swelling and prevent infection.[9]

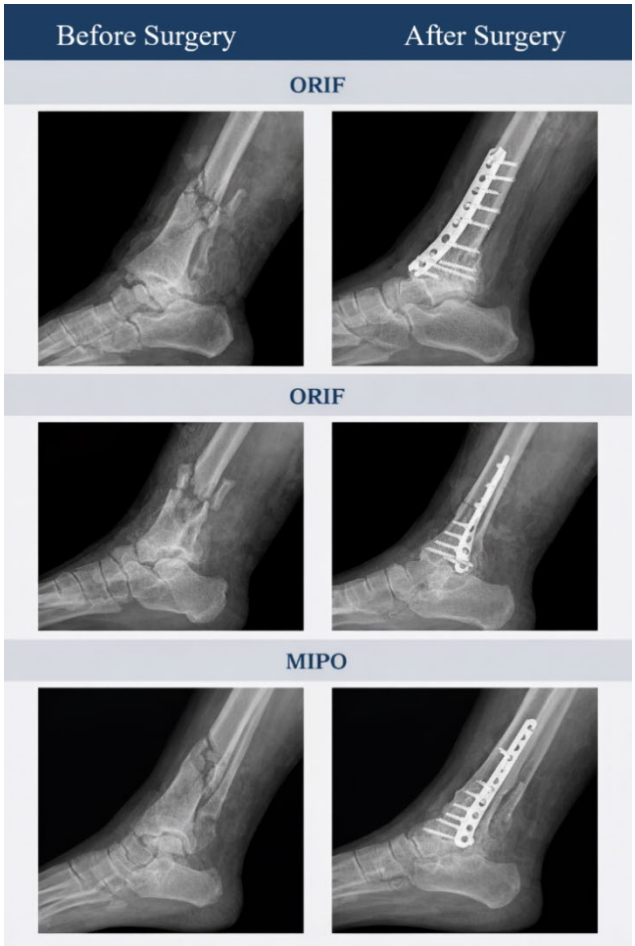

Figure 1 .Representative ankle radiographs demonstrating a pilon fracture and two operative treatment strategies.

Although conventional open reduction and internal fixation (ORIF) can achieve anatomical alignment, it is associated with increased soft tissue morbidity, which in turn raises the risk of postoperative complications.[10] Present advances in the technique of fixation, such as minimally invasive plate osteosynthesis (MIPO) and external fixation, are oriented towards minimizing soft tissue disruption and have been promising for enhancing patient outcomes.[11] Although other outcome measures have been employed in pilon fracture recovery assessment, such as AOFAS score and SF-36, the Foot Function Index (FFI) is a more specific measure of pain, disability, and lower limb functional limitation and is thus especially useful in postoperative foot and ankle disease tracking.[12] These surgical innovations have been paralleled by a growing emphasis on early intervention and structured postoperative rehabilitation protocols, which are critical for optimal functional recovery. But results after treatment are still extremely variable and depend upon healthcare facilities, surgical skill, and compliance with rehabilitation guidelines. Therefore, context-specific studies are needed to identify real-world outcomes and inform practice in various clinical settings. Outcome variability is also influenced by differences in treatment protocols, patient comorbidities, and socioeconomic factors, all of which may affect access to rehabilitation services and adherence to postoperative care.[13-15]

In the face of global advances in surgical methods, few data have been reported from low- and middle-income nations like Iran on real-world results and complication rates after pilon fracture surgery. Variability in access to healthcare, surgeon expertise, and rehabilitation protocols can result in intercountry and intracountry variability in outcomes. There is also an increasing requirement for the formulation of evidence-based standardised treatment protocols to inform decision-making in these injuries, particularly within resource-constrained settings. This is the first Iranian study to measure clinical outcome after pilon fracture surgery in the context of the Foot Function Index (FFI) and to evaluate postoperative complications in all aspects under real-world circumstances. Furthermore, there is no extensive longitudinal study in Iran with patient-reported outcomes measured with valid tools at various follow-up periods following pilon surgery. In this study, the said deficiency is to be addressed through the establishment of robust clinical and functional outcome data.

Materials & Methods

Study Design and Setting

This prospective observational study was performed between August 2020 and March 2024 at two teaching hospitals affiliated with Isfahan University of Medical Sciences, namely Kashani Hospital and Alzahra

Hospital, which are the principal referral centers for orthopedic trauma in the region. A consecutive sampling method was used to enroll all eligible patients presenting with pilon fractures during the study period. The needed sample size was 80 participants, using effect size information from prior studies, with 80% power and an alpha of 0.05, to provide adequate statistical power to detect clinically significant differences in functional outcomes.
Ethical Considerations: Written informed consent for surgery and inclusion in the study was obtained from all the participants.

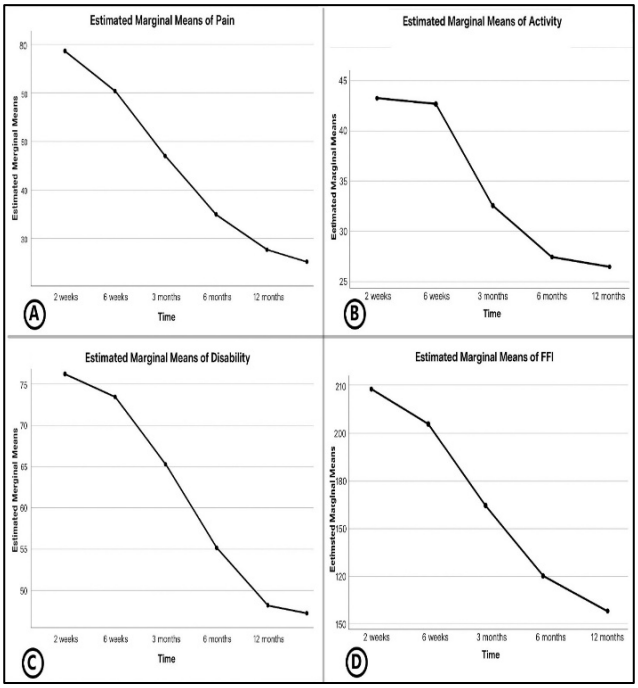

Figure 2. Longitudinal Changes in Pain, Disability, and Activity Limitation Domains of the Foot Function Index (FFI) at 2 Weeks, 6 Weeks, 3 Months, 6 Months, and 12 Months Postoperatively

Patient Evaluation and Fracture Classification

All the patients were assessed pre-operatively by a senior orthopedic surgeon on the basis of proper history-taking, physical examination, and radiological investigation. All surgeries were performed or supervised by fellowship-trained orthopedic trauma surgeons to ensure consistency in surgical technique and clinical judgment. Fractures were classified according to the AO/OTA (Arbeitsgemeinschaft für Osteosynthesefragen/Orthopaedic Trauma Association) system into types A (extra-articular), B (partial articular), and C (complete articular) fractures.[16]

Inclusion criteria

Patients could be included if they had the following: age ≥16 years; confirmed diagnosis of a type B or C pilon fracture (AO/OTA classification); surgical indication; and ≤21 days' time lapse between injury and operation. Only closed fractures were included. Patients must also be capable of giving informed consent and undergoing follow-up evaluation.

Exclusion criteria

Exclusion criteria included previous operation or deformity of the affected ankle; open fracture; polytrauma with ICU admission; pathological fractures; and any medical condition making normal follow-up unsuitable (e.g., dementia, relocation). Patients withdrew consent, failed to attend more than two scheduled follow-up visits, or had missing Foot Function Index (FFI) data and were excluded from final analysis.

All admission and exclusion criteria were met by the admitting assessment orthopedic surgeon at admission through a standardized checklist.

Surgical Procedures and Postoperative Protocol

The choice of surgical technique, open reduction and internal fixation (ORIF), minimally invasive plate osteosynthesis (MIPO), or primary ankle arthrodesis, was determined by the treating orthopedic surgeon based on fracture type and soft tissue condition. In particular, ORIF was mostly chosen in cases that had extensive articular comminution or displacement, which necessitated direct visualization for anatomic reduction of the joint surface. Conversely, MIPO was preferred in cases with somewhat well-preserved joint congruity, metaphyseal fractures with feasible indirect reduction, or compromised soft tissue, with the aim of avoiding additional injury to the soft tissues. The final choice was made in the operating room. Post-operatively, thromboprophylaxis with low-molecular-weight heparin and peri-operative antibiotic prophylaxis was administered. On the first post-operative day, an open-foot brace to keep the ankle in the neutral (90°) position was applied. Active and passive range of motion, along with strengthening of the muscles, was encouraged to avoid such complications as equinus contracture. Weight-bearing was customarily deferred until roentgenographic proof of union was established, and progressive ambulation was managed by virtue of parametric physiotherapy protocols on follow-up examinations.

Data Collection and Follow-up

The postoperative data collected were age, gender, type of fracture, and type of surgical procedure. FFI was employed to assess outcome, as well as symptom reporting of complications including nonunion, wound complication, infection, loosening of the implant, and revision surgery. 2 weeks, 6 weeks, 3 months, 6 months, and 12 months postoperative follow-up assessments were conducted using clinic visits or structured telephone interviews. Patients with incomplete follow-up or missing FFI data at more than two time points were excluded from the final analysis to preserve data integrity.

Foot Function Index (FFI) Assessment

The Persian version of the Foot Function Index (FFI) was used as a validated instrument to measure pain, disability, and activity limitation subscales.[17] The items were completed on a 0 (no difficulty) to 10 (severe difficulty) scale, where a higher score reflects more impairment. Pain and disability domains were both given a score of 90, and activity limitation a score of 50 at maximum. A measure of functional recovery to pre-injury level was used in the form of returning to daily and occupational activities. The FFI was chosen because of its high validity in measuring foot pain and disability in orthopedic trauma populations, and the existence of a culturally adapted Persian form.

Statistical Analysis

Statistical comparison was performed using the SPSS software (version 26.0, IBM Corp., Armonk, NY, USA). Categorical data were expressed as frequencies and percentages, whereas continuous data were expressed as mean±SD. Repeated measures ANOVA was used to compare differences in FFI scores over follow-up periods. Pearson or Spearman correlation coefficients were used, depending upon the distribution of the variables, to measure association. Two-tailed P-value <0.05 was used for statistical significance.

Results

Patient Demographics and Fracture Classification

The study included 183 patients, 146 men (79.8%) and 37 women (20.2%). The average age of the patients was 37.47 years, with a range of 10.53 years. According to the AO/OTA classification, 118 patients (64.5%) had C3 fractures, 17 (9.3%) had C2 fractures, 32 (17.5%) had C1 fractures, 8 (4.4%) had B2 fractures, and 8 (4.4%) had B1 fractures. Out of 190 initially enrolled patients, 183 completed at least 80% of follow-up assessments and were included in the final analysis. The follow-up completion rate at 12 months was 96.3%. The number of patients who had staged surgery was 118(64.5%), and 65(35.5%) patients had primary surgery. Staged surgery was mainly chosen for those patients who arrived with extensive soft-tissue swelling, fracture blisters, or high-energy comminuted fractures (especially AO/OTA type C3). These patients underwent initial temporary external fixation to regain alignment and facilitate soft-tissue recovery before undergoing definitive internal fixation once local soft-tissue conditions were judged suitable. Temporary external fixation was done solely in the patients who underwent staged surgery, primarily for high-energy fractures and associated soft tissue injuries. The temporary external fixator allowed for the restoration of limb alignment and associated soft tissue recovery prior to definitive fixation. The mean time required for external fixation was 12±3 days (range: 7-21 days), following which definitive ORIF or MIPO was carried out once the soft tissues were amenable. Surgical techniques included open reduction and internal fixation (ORIF) in 139 patients (76.0%) and minimally invasive plate osteosynthesis (MIPO) in 44 patients (24.0%) (Table 1).

Table 1: Baseline Demographic Characteristics, Fracture Classification, and Surgical Procedures of the Study Population

Variables	Frequency	
Sex	Male	146(79.8%)
	Female	37(20.2%)
Age	Mean (year)	37.47±10.53
	<20	4(2.2%)
	20-30	55(30.1%)
	30-40	53(29.0%)
	40-50	48(26.2%)
	50-60	18(9.8%)
	>60	5(2.7%)
Pilon Fracture Type	B1	8(4.4%)
	B2	8(4.4%)
	C1	32(17.5%)
	C2	17(9.3%)
	C3	118(64.5%)
Surgery Staging	Primary	65(35.5%)
	Staged	118(64.5%)
Surgery Procedure	External Fixation	63(34.42%)
	ORIF	139(76. %)
	MIPO	44(24.0%)

Functional Outcome Measures (FFI Scores)

The average scores on the Foot Function Index (FFI) pain subscale were 86.51±3.25 at 2 weeks, 77.95±6.41 at 6 weeks, 64.44±4.58 at 3 months, 53.20±3.69 at 6

months, and 51.10±2.73 at 1 year after surgery. The activity subscale (45.96±1.72 to 39.11±2.09) and disability subscale (74.80±2.81 to 54.88±2.93) exhibited similar trends with respect to time, indicating improvement in function. The composite FFI score improved from 207.27±7.79 at 2 weeks to 145.09±7.75 at 1 year, which indicates that major function was regained (Figure 1). Generally, the FFI scores showed a persistent downward trend in all domains, reflecting sustained improvements in pain, functional disability, and activity limitation during the 12-month follow-up. A similar trend was also seen in functional outcomes. Patients with more severe fractures (AO/OTA type C3) had higher scores on the FFI scale in the early follow-up period, suggesting higher pain and functional disability, while patients with less severe fractures recovered functionally faster. However, the statistical comparison was not feasible due to the smaller subgroup size.

Postoperative Complications

Postoperative complications involved non-union in 56 patients (30.6%), malunion in 42 (23.0%), and loosening of the implant in 27 (14.8%). Revision surgery was also needed in 67 patients (36.6%). Infection rates were superficial infection in 78 patients (42.6%), deep infection in 29(15.8%), and pin site infection in 62(33.9%). Within the first six months after surgery, most functional improvement took place, and scores subsequently stabilized, especially in the pain and composite domains. Osteoarthritis accounted for 35 patients (19.1%), whereas other rare complications were skin necrosis (4 cases, 2.18%) and one case of amputation of the limb (0.54%). Patients who underwent MIPO demonstrated a lower incidence of deep infection (9.1%) compared to those treated with ORIF (17.3%), though this difference was not statistically significant (P=0.082) (Table 2).

When outcomes were descriptively analyzed based on the fracture type, patients with more complex fracture patterns, specifically AO/OTA C3 fractures, were found to have higher rates of postoperative complications, such as nonunion, malunion, deep infection, and the need for revision surgery, than those with less complex fracture patterns (B and C1-2 fractures). As a result of the uneven distribution of fracture types, statistical analysis was not conducted.

Statistical Analysis of Outcome Trends

Repeated measures ANOVA revealed statistically significant changes across all the FFI subscales. Pain scores fell significantly over time (P<0.001), with further improvement up to 6 months after surgery. Disability scores improved significantly between 6 weeks and 6 months (P<0.001), but the changes between 6 months and 1 year were not statistically significant (P=1.00). Activity scores did not vary much with non-significant differences between intervals like 2 and 6 weeks (P=1.000) and 6 months and 1 year (P=1.00). Composite FFI scores also showed the same pattern with significant decline till 6 months (P<0.001) and no change thereafter.

Recovery Duration and Correlation with Age

The mean functional recovery time to normal daily activity was 25.48±7.48 weeks. Missing data for FFI scores at individual time points were handled using pairwise deletion. No imputation methods were used. There was significant variation in recovery time among the patients, as indicated by the duration to the return to the activities of daily life, which ranged from 14 to 41 weeks (interquartile range: 21–29 weeks). Age was directly correlated with 6-week postoperative FFI scores (r=0.208, P=0.005), indicating a more sluggish early recovery in the older patient. Age was also significantly correlated with increased numbers of complications (r=0.585, P<0.001), indicating age-specific surgical and rehabilitative care. In exploratory analyses, other variables which may have also influenced recovery time were considered, such as fracture severity, timing of definitive surgery, type of surgery (ORIF versus MIPO), and occurrence of major complications. More complex fractures and the development of complications were associated with delayed recovery. However, age continued to be associated with delayed early functional recovery. Because of the observational nature of the study and lack of sufficient statistical power to fully adjust for variables in a comprehensive manner, it was not possible to rule out the confounding effects of variables under consideration in assessing the association between age and recovery time.

Discussion

Pilon fractures, although uncommon, still rank among the most challenging orthopedic injuries because of their common articular involvement, compromise of soft tissues, and comminution of fracture patterns. Successful operative management requires careful planning, accurate anatomical reduction, and careful fixation techniques to avoid complications and optimize recovery.[18]

Our study, with 183 patients and follow-up at 12 months, found demographic trends and outcomes consistent with the literature. Most patients were younger men, as expected in the high-energy

mechanisms of trauma, most commonly associated with pilon fractures, such as motor vehicle accidents and falls from height. Better recovery rates also existed in younger patients, presumably due to increased healing capacity and lower comorbidities.[19-23] This is in line with other studies that have suggested that the rate of functional recovery reported by patients with pilon fractures is greatest in the early postoperative period, followed by a slower rate of improvement over time. This has important implications for the role of early postoperative rehabilitation and patient compliance in the first months after surgery in functional recovery.

Table 2: Postoperative Complications Observed During the 12-Month Follow-up Period After Surgical Treatment of Pilon Fractures

Variables	Frequency	
Complications	Non-union	56(30.6%)
	Malunion	42(23. %)
	Loose devices	27(14.8%)
	Revision surgery	67(36.6%)
	Superficial infection	78(42.6%)
	Deep infection	29(15.8%)
	Pin Site Infection	62(33.9%)
	Osteoarthritis	35(19.1%)
	Skin Necrosis	4(2.18%)
	Amputation	1(0.54%)
Daily routine recovery	Mean	25.63±7.48

The most common fracture pattern in our series was AO/OTA C3, a multi-fragmentary, complex fracture with the worst prognosis and complication rate. They are most commonly treated by staged operations and most commonly treated by ORIF, the most employed technique in the world.[24] But similar to earlier research, ORIF has also been shown to be at increased risk for complications like infection and nonunion, particularly with high-energy fractures.[21] The severity of fracture, as per AO/OTA classification, was identified as a significant predictive factor for functional outcomes and complications in our patient population. Patients with C3 fractures had worse functional recovery and higher rates of complications than those with lower complexities of fractures. This finding is consistent with previous studies that had found poor functional outcomes in highly comminuted pilon fractures. The main benefits of minimally invasive procedures are believed to be due to the less disruption of soft tissues and maintenance of the periosteal blood supply. However, sound patient selection is important, especially in complex intra-articular fractures where direct visualization may be necessary for achieving adequate reduction.

Postoperative complications in our series included nonunion (30.6%), malunion (23%), and deep infection (15.8%). These are comparable to those found in high-resource nations. For instance, a systematic review of 484 pilon fractures treated with ORIF demonstrated deep infection rates of about 13.8%.[25] Our findings confirm that infection risk is directly associated with fracture severity, timing of operation, and soft tissue management. This similarity may reflect the growing adherence to staged surgical protocols and improved soft tissue handling, even in resource-limited settings. The fairly high incidence of staged management in our series is largely a reflection of the predominantly high-energy injuries with severe soft-tissue damage. Such a strategy is highly recommended for its efficacy in lowering the incidence of wound complications and deep infections, especially in the setting of pilon fractures.

The study revealed that the most prevalent complications included superficial infection, nonunion, malunion, pin site infection, and the necessity for a second surgery. Previous research also highlighted superficial infection as a frequent complication in this type of surgery.[19, 21] Nonunion and malalignment were also commonly reported issues among patients with C3-type fractures and those who underwent ORIF surgery, the most common type of fracture and surgery, respectively. Additionally, our results provide further evidence for the importance of fracture severity, as described by the AO/OTA classification system, in terms of functional outcome and the risk of complications. Those patients who had highly comminuted fractures of the C3 type had a consistently worse early functional outcome, reflecting the difficulties of restoring articular surface congruity. Soft tissue infections were common, possibly due to impaired wound healing, diminished perioperative care, and patient risk factors including smoking, diabetes, and hygiene. These kinds of infections can be related to the personal hygiene and compliance of the patients. Previous studies reported that the most influential variables in the outcome prognosis of the surgery are fracture type and age, which are also related to the current study.[1, 19-22, 24, 26, 27]

Foot Function Index (FFI), the outcome measure that we used for the measurement of functional outcomes, was sensitive and valid in measuring post-operative recovery among Iranian patients. All three aspects, pain, disability, and activity limitation, improved

significantly, most notably in the first 6 months, followed by relative stabilization.[17] These findings suggest that structured rehabilitation within the first six months is critical to maximizing recovery, and that patient follow-up should be prioritized during this window. This trend was consistent with other prospective studies that had used PROMIS or FFI for post-operative assessment.[20]

Strengths of our study are a fairly large sample size for a single-center trial and prospective follow-up. Use of a validated outcome measure (FFI) and representation of a broad spectrum of fracture types (B and C) enhances the external validity of our findings. We present real-world complication rates, yielding clinically useful information regarding surgical risk stratification and planning. This research has a few limitations. It was carried out at one tertiary center and is therefore likely to be restricted in external validity to other environments. Non-randomized design imposes a risk of selection bias on the treatment allocation. Radiologic outcomes were not measured, although the functional outcome of recovery was determined with a well-validated Foot Function Index (FFI). Exclusion of patients with open fractures and polytrauma limits applicability to more severe cases. In addition, long-term post-12-month complications, such as post-traumatic arthritis, were not possible to evaluate. Adherence to postoperative rehabilitation protocols, which was variable and not objectively assessed, may also have had an effect on functional outcomes.

This is the first Iranian study to evaluate pilon fracture results against the Foot Function Index. Subsequent studies should have longer follow-up and radiologic examination in an attempt to better relate anatomical healing to functional results.

Conclusion

This research illustrates that surgically managed intra-articular pilon fractures with ORIF or MIPO methods yield considerable functional recovery through 12 months of follow-up, supported by progressive improvement in Foot Function Index (FFI) scores. Most of the functional improvement happens within six months postoperatively, followed by a plateau. Despite these advances, the complication rate in the form of nonunion, malunion, infection, and reoperation is high, particularly with complex fractures like AO/OTA type C3.

Age was revealed to be an important prognostic factor, with rapid recovery and fewer complications in young patients. The findings highlight the need for age-specific surgical methods and postoperative rehabilitation programs.

Finally, this study emphasizes the use of early intervention, careful operative planning, and systematic follow-up to achieve the best outcome for patients with pilon fractures. Long-term follow-up, multicenter, large-scale, randomized studies with correlation of radiologic outcome are suggested to confirm and extrapolate these results.

Acknowledgement

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Ethical Issues

The study design was approved by the Ethics Committee of Isfahan University of Medical Sciences (IR.MUI.MED.REC.1401.385), and the writers disclosed any ethical concerns during the study.

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Conflicts of Interest

The authors of the present paper have declared that they have no conflicts of interest.

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