Development of Minimally Invasive Strategies for Tibial Pilon Fractures

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Abstract

Aim: The research evaluates minimally invasive surgical techniques for tibial pilon fractures through AO/OTA classification while assessing clinical and radiological results and determining predictive elements.

Methods: Between January 2019 and December 2022, 30 patients (18 males, 12 females) diagnosed with AO/OTA type 43-B and 43-C tibial pilon fractures and treated with minimally invasive surgery were retrospectively analysed. Patients were treated with percutaneous fixation (n=14) or minimally invasive plate osteosynthesis (n=16). The AOFAS score and pain VAS score and SF-36 were used to evaluate functional outcomes while articular reduction and joint step and alignment measurements were used to evaluate radiological outcomes.

Results: The mean patient age was 45±12 years, and the mean follow-up period was 24 months. The rate of anatomical reduction was significantly higher in Type B fractures (87.5%) compared to Type C fractures (57.1%) ($p=0.008$). AOFAS scores reached an average of 85±8 at 12 months but decreased significantly with increasing AO/OTA classification ($\beta=-0.45$, $p=0.001$). The risk of post-traumatic arthritis was significantly increased in AO type C2/C3 fractures (OR=6.8, $p<0.001$) and in cases with joint step-off >2 mm (OR=7.5, $p<0.001$).

Conclusions: The treatment of tibial pilon fractures benefits from minimally invasive surgical approaches. The AO/OTA classification demonstrates prognostic value because functional and radiological outcomes worsen as fracture complexity increases. The surgical approach needs to be tailored based on the fracture pattern and individual patient factors.

***Keywords**: Fracture fixation, minimally invasive; tibial fractures*

1. Introduction

Tibial pilon fractures are rare but high-morbidity injuries involving the distal tibial joint surface. The incidence of these fractures amounts to 1% of all lower extremity fractures and they usually result from high-energy trauma such as motor vehicle accidents and falls from height.[1] The fractures predominantly affect active males between 30 and 50 years old and present significant surgical challenges because of severe soft tissue damage.[1] The classification of fractures serves as a crucial factor for determining treatment approaches. The AO/OTA classification system divides fractures into three categories: 43-A (extra-articular), 43-B (partially intra-articular) and 43-C (completely intra-articular).[2] The Rüedi-Allgöwer classification system groups' fractures according to fragmentation severity into three types: Type I (non-displaced), Type II (displaced) and Type III (severely comminuted).[2]

The traditional preference for open reduction and internal fixation (ORIF) exists but surgeons encounter frequent deep infections and wound complications because of extensive incisions.[3] A stepwise treatment' approach was developed because of these issues. The first stage of treatment involves applying temporary external fixation to enable soft tissue recovery before performing definitive surgery.[3] The new approach has led to a substantial decrease in surgical complications. The medical field has adopted minimally invasive techniques including percutaneous fixation and MIPO as alternative treatments to traditional surgical approaches during the recent years. The skin incision remains small in these techniques while the periosteum stays intact and blood circulation remains supported and wound complications decrease.[4] The available literature demonstrates that MIPO procedures result in infection rates below 1% and most patients achieve favourable functional results.[4]

The risk of postoperative complications remains high in tibial pilon fractures. The complications of superficial or deep infection, non-union, malunion, post-traumatic arthritis, and frozen ankle may occur.[5] The rate of return to work is low, and quality of life is significantly impacted for an extended period.[6] Therefore, long-term rehabilitation is as critical as treatment planning. This study aims to evaluate the clinical and radiological outcomes of minimally invasive surgical techniques in tibial pilon fractures. Factors related

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to fracture classification, patient characteristics, and complications will be analysed, and the efficacy and limitations of these approaches will be discussed.

2. Materials and Methods

2.1. Study Population and Sample

This study includes a retrospective analysis of patients diagnosed with tibial pilon fractures and treated with minimally invasive surgical techniques at our clinic between January 2019 and December 2022. The sample size was determined to be at least 28 patients based on calculations for the primary endpoint (AOFAS score) with a 5% margin of error and 80% power. A total of 30 patients were included in the study to account for safety margins. Inclusion criteria: Age 18 years or older, diagnosis of a type 43-B or 43-C tibial pilon fracture according to the AO/OTA classification, treatment with minimally invasive surgical techniques (percutaneous fixation or minimally invasive plate osteosynthesis), and availability of at least 12 months of follow-up data. The study excluded patients with open fractures and pathological fractures and those who had previous surgery on the same extremity and neurovascular injury and systemic bone metabolism disorders (osteoporosis, Paget's disease, etc.) and active infection and inability to cooperate and inability to adhere to the follow-up protocol. The following operational definitions were used for variables: AO/OTA and Rüedi-Allgöwer classifications were used for fracture classification, soft tissue damage was graded according to the Tscherne classification, and functional outcomes were evaluated using the AOFAS (American Orthopaedic Foot and Ankle Society) score.

2.2. Study Procedures

Patient data were collected from our hospital's electronic medical record system and archived patient files. The preoperative assessment included demographic details (age, gender, BMI) and comorbidities and trauma mechanism and time to surgery. Fracture classification was performed by two independent orthopaedic specialists using anteroposterior and lateral radiographs and computed tomography (CT) images. In case of disagreement, a third expert opinion was sought. Surgical reports provided the information about the operation duration and intraoperative blood loss and fluoroscopy time and complications. Postoperative follow-ups were performed at 3, 6, 12, and 24 months, with each follow-up including radiographic evaluation (anatomical reduction, articular step-off, varus/valgus alignment deformity, union status), joint range of motion, pain assessment (VAS score), time to full weight-bearing, and complications. Radiographic measurements were performed by two independent observers using PACS (Picture Archiving and Communication System), and mean values were obtained. Inter-observer reliability was assessed using Cohen's kappa coefficient and found to be 0.85.

2.3. Surgical Technique Details

Patients were treated with one of two surgical techniques based on fracture type and soft tissue condition: percutaneous fixation (n=14) or minimally invasive plate osteosynthesis (MIPO) (n=16). The surgeon used clinical characteristics to determine group distribution but did not perform randomization. All surgical procedures were performed by two orthopaedic specialists with at least five years of experience in tibial pilon fractures. In the percutaneous fixation technique, fracture fixation was achieved using cannulated screws and K-wires after closed reduction. In the MIPO technique, after joint surface reconstruction through a 3-4 cm minimal incision over the medial malleolus, a tunnel was created without peeling the periosteum, and a 3.5 mm locked plate was placed. The surgical team maintained the fracture hematoma during both procedures while using fluoroscopy to evaluate the quality of reduction during surgery. The postoperative protocol started with plaster cast application during the first two weeks followed by early passive movement initiation and partial/full weight-bearing protocol based on clinical and radiological healing findings. Full weight-bearing was initiated at 8-10 weeks in the percutaneous fixation group and at 10-12 weeks in the MIPO group.

2.4. Statistical Analysis

Data analysis was performed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). The study presented categorical data through numbers and percentages while showing continuous data as mean values with standard deviations (SD). The Shapiro-Wilk test evaluated the normality of data distribution. The independent samples t-test and one-way analysis of variance (ANOVA) were used to compare variables with normal distribution but Mann-Whitney U test and Kruskal-Wallis test were used for variables that did not follow a normal distribution. The analysis of categorical variables used either chi-square or Fisher's exact test. The relationship between AO/OTA classification and outcome variables was evaluated through Spearman rank correlation analysis. The research used multivariate linear regression analysis to determine independent factors that influence functional outcomes and logistic regression analysis to determine risk factors for complications. Kaplan-Meier survival analysis was used to analyze the boiling time. The study used P values less than 0.05 to determine statistical significance. Actual P values were expressed as two digits (e.g., $P=0.04$) for $P\geq0.01$ and three digits (e.g., $P=0.008$) for $P<0.01$, unless $P<0.001$. Values with $P<0.001$ were reported as $P<0.001$ instead of the exact value. Missing data were not excluded from the study; data loss was reported in 3 patients (10%) at the 24-month follow-up, and the last observation carried forward (LOCF) method was used in statistical analyses. The study conducted subgroup analyses to evaluate fracture types (AO/OTA 43-B vs 43-C) and surgical techniques (percutaneous fixation vs MIPO) and complications presence. The power of the cross-sectional study was assessed using a post-hoc power analysis and confirmed to be sufficient for 80% power.

2.5. Ethical Considerations

This study was approved by the Clinical Research Ethics Committee of our hospital on 10 December 2018 with decision number 2018/347. Written informed consent was obtained from all patients included in the study. The researchers protected patient privacy through anonymization and coding of personal data before conducting analysis. The study team-maintained data security through encrypted computers and databases which they could access exclusively. The study followed both Helsinki Declaration principles and Good Clinical Practice guidelines during its execution.

3. Results

The research involved thirty patients who received tibial pilon fractures treatment using minimally invasive surgical methods. The patient population consisted of 45 ± 12 years old individuals with a predominance of males (60%). The majority of patients experienced high-energy trauma incidents that match the common origins of complex fractures (67%). A considerable number of patients presented with comorbidities with smoking being the most common at 33% followed by hypertension at 27% and diabetes at 20%. Type B fractures outnumbered Type C fractures by 53 to 47 according to the AO/OTA classification system with 43-B2 being the most common subtype at 30% (Table 1).

Table 1

Demographic and Baseline Characteristics

Characteristic	Value
Age (years)	45 ± 12 (Range: 18-75)
Gender (M/F)	18/12
BMI (kg/m²)	26.8 ± 4.3 (Range: 19.5-34.2)
Comorbidities (n, %)	
- Diabetes	6 (20%)
- Hypertension	8 (27%)
- Smoking	10 (33%)
- Osteoporosis	4 (13%)
Mechanism of Injury (n, %)	
- High-energy (e.g., RTA)	20 (67%)
- Low-energy (e.g., fall)	10 (33%)
Time from Injury to Surgery (days)	5 ± 3 (Range: 1-14)
AO/OTA Classification (n, %)	
- 43-B1	7 (23%)
- 43-B2	9 (30%)
- 43-C1	6 (20%)
- 43-C2	5 (17%)
- 43-C3	3 (10%)
Rüedi-Allgöwer Classification (n, %)	
- Type I	8 (27%)
- Type II	14 (47%)
- Type III	8 (27%)
Soft Tissue Status (Tscherne Classification)	
- Grade 0	4 (13%)
- Grade 1	16 (53%)
- Grade 2	10 (33%)

Table 2

Surgical Details

Characteristic	Value	p-value
Minimally Invasive Technique Used (n, %)		
- Percutaneous Fixation	14 (47%)	
- MIPO (Minimally Invasive Plate Osteosynthesis)	16 (53%)	
Duration of Surgery (minutes)*	70 ± 20 (Range: 50-110)	
Intraoperative Blood Loss (mL)*	150 ± 40 (Range: 80-220)	
Fluoroscopy Time (seconds)*	112 ± 35 (Range: 65-180)	0.03[a]
Fixation Method (n, %)		
- Locking plate	18 (60%)	
- Cannulated screws	8 (27%)	
- K-wires + external fixation	4 (13%)	
Intraoperative Complications (n, %)		
- None	24 (80%)	
- Minor complications (e.g., superficial bleeding)	4 (13%)	
- Major complications (e.g., hardware malposition)	2 (7%)	
Hospital Stay (days)	5.8 ± 2.3 (Range: 3-12)	0.01[b]

**Values presented as mean ± SD*
[a] Kruskal-Wallis test across AO/OTA classification groups
[b] One-way ANOVA across Rüedi-Allgöwer classification groups

The surgical procedures were divided between percutaneous fixation (47%) and minimally invasive plate osteosynthesis (MIPO) (53%). The mean duration of surgery was 70 ± 20 minutes with an average intraoperative blood loss of 150 ± 40 mL. Fluoroscopy exposure during surgery averaged 112 ± 35 seconds but showed substantial differences based on AO/OTA classification categories (p=0.03) and more complex fractures needed extended imaging duration. The most commonly used fixation method consisted of locking plates which accounted for 60% of the total followed by cannulated screws at 27%. The majority of procedures (80%) finished without any intraoperative issues yet patients stayed in the hospital for an average duration of 5.8 ± 2.3 days (Table 2).

Functional recovery showed a steady advancement during the entire period of observation. The percentage of patients who achieved full weight-bearing status rose from 33% at three months to 67% at six months before reaching 93% at twelve months. The AOFAS scores increased by 20 points during the study period from 65 ± 10 at three months to 85 ± 8 at twelve months. Ankle range of motion consistently improved as patients achieved 16° ± 6° dorsiflexion at twelve months starting from 8° ± 4° at three months. Most patients regained the ability to work after successful functional rehabilitation because return to work rates increased from 13% at three months to 83% at twelve months (Table 3).

The multivariate regression analysis identified multiple variables that strongly influenced the achievement of functional results. AOFAS scores at 12 months had negative associations with both AO/OTA classification (β=-0.45, p=0.001) and age (β=-0.32, p=0.008) and also with time to surgery (β=-0.28, p=0.01) and articular step-off (β=-0.38, p=0.004).

The duration of bone union increased with higher AO/OTA classification (β=0.52, p<0.001) as well as with smoking status (β=0.35, p=0.005) and diabetes (β=0.30, p=0.01). Complications were most likely to occur in patients with higher AO/OTA classification scores (β=0.48, p=0.001) and higher BMI (β=0.33, p=0.006) and worse soft tissue condition (β=0.42, p=0.002). The models showed strong explanatory capabilities since the adjusted R^2 values reached between 0.58 to 0.68 (Table 4).

The relationship between fracture classification and functional outcomes demonstrated a distinct pattern throughout all assessment parameters. Fracture severity progression from 43-B1 to 43-C3 resulted in AOFAS scores decreasing from 89±5 to 68±9 while pain scores (VAS) rose from 1.8 to 4.5. Fracture complexity progression from 43-B1 to 43-C3 led to longer union times with the most severe fractures requiring 18 weeks to heal. The SF-36 Physical Component scores decreased progressively throughout the classification groups with statistical differences observed in all parameters (p<0.01) (Figure 1).

Postoperative complications were found in 19 patients (63.3%) with hardware irritation being the most prevalent at 16.7% followed by delayed union at 13.3% and superficial infection at 10% and post-traumatic arthritis at 10%. Multivariate analysis revealed distinctive risk factors for each complication type. The risk of superficial infections was significantly higher among diabetic patients (OR 3.2, 95% CI: 1.4-5.8, p=0.01) but type C3 fractures and smoking were strong predictors of delayed union (OR 4.5, 95% CI: 2.1-8.2, p=0.003 and OR 3.1, 95% CI: 1.5-6.4, p=0.01 respectively). The combination of AO type C2/C3 fractures with articular step-off >2mm was strongly linked to post-traumatic arthritis with OR 6.8 (95% CI: 3.2-12.5, p<0.001) and OR 7.5 (95% CI: 3.5-15.2, p<0.001) respectively (Table 5).

Table 3

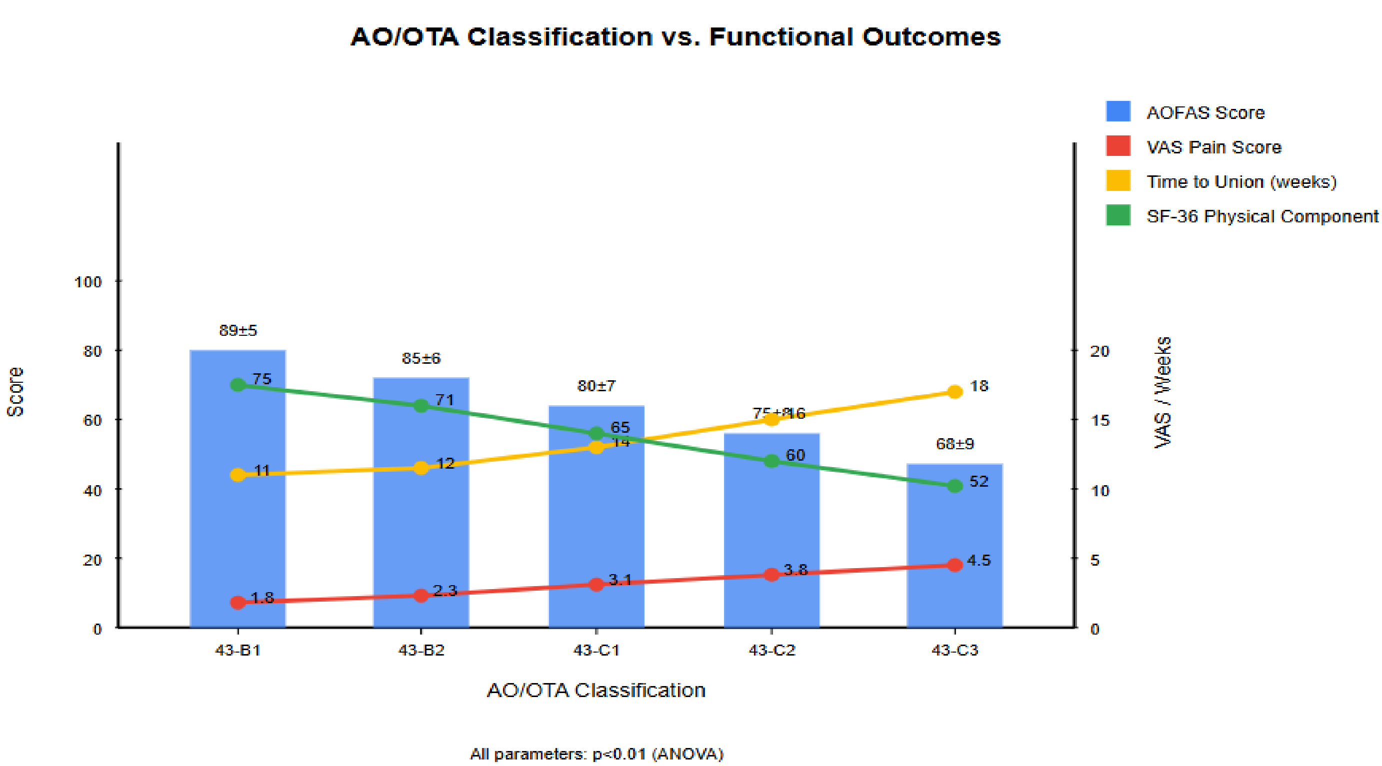
Functional Recovery Timeline

Follow-up Time (months)	Dorsiflexion (°)	Plantarflexion (°)	Weight-bearing Status (n, %)	AOFAS Score (Mean ± SD)	RTW (n, %)*
3	8 ± 4	15 ± 6	Full: 10 (33%) Partial: 15 (50%) None: 5 (17%)	65 ± 10	4 (13%)
6	12 ± 5	25 ± 8	Full: 20 (67%) Partial: 8 (27%) None: 2 (6%)	75 ± 12	15 (50%)
12	16 ± 6	32 ± 7	Full: 28 (93%) Partial: 2 (7%) None: 0 (0%)	85 ± 8	25 (83%)
24[a]	18 ± 5	35 ± 6	Full: 29 (97%) Partial: 1 (3%) None: 0 (0%)	86 ± 7	26 (87%)

**RTW = Return to Work*
[a] Data available for 27 patients at 24-month follow-up (10% loss to follow-up)

Figure 1

AO/OTA Classification vs. Functional Outcomes:



Bar chart and line graph showing the relationship between fracture classification and outcome measures. AOFAS (American Orthopaedic Foot and Ankle Society) scores decrease while VAS (Visual Analog Scale) pain scores and time to union increase with increasing fracture complexity. SF-36 (Short Form-36) Physical Component scores show progressive decline from type B to type C fractures. All parameters show statistically significant differences (p<0.01).

Table 4

Multiple Regression and Correlation Analysis

Dependent Variable	Independent Predictors	Standardized β	95% CI	p-value	Adjusted R^2
AOFAS Score at 12 months	AO/OTA Classification	-0.45	-0.62 to -0.28	0.001	0.68
	Age	-0.32	-0.48 to -0.16	0.008	
	Time to Surgery	-0.28	-0.44 to -0.12	0.01	
	Articular Step-off	-0.38	-0.54 to -0.22	0.004	
Time to Union	AO/OTA Classification	0.52	0.35 to 0.69	<0.001	0.62
	Smoking Status	0.35	0.18 to 0.52	0.005	
	Diabetes	0.30	0.13 to 0.47	0.01	
Complication Rate	AO/OTA Classification	0.48	0.31 to 0.65	0.001	0.58
	BMI	0.33	0.16 to 0.50	0.006	
	Soft Tissue Status	0.42	0.25 to 0.59	0.002	

Table 5

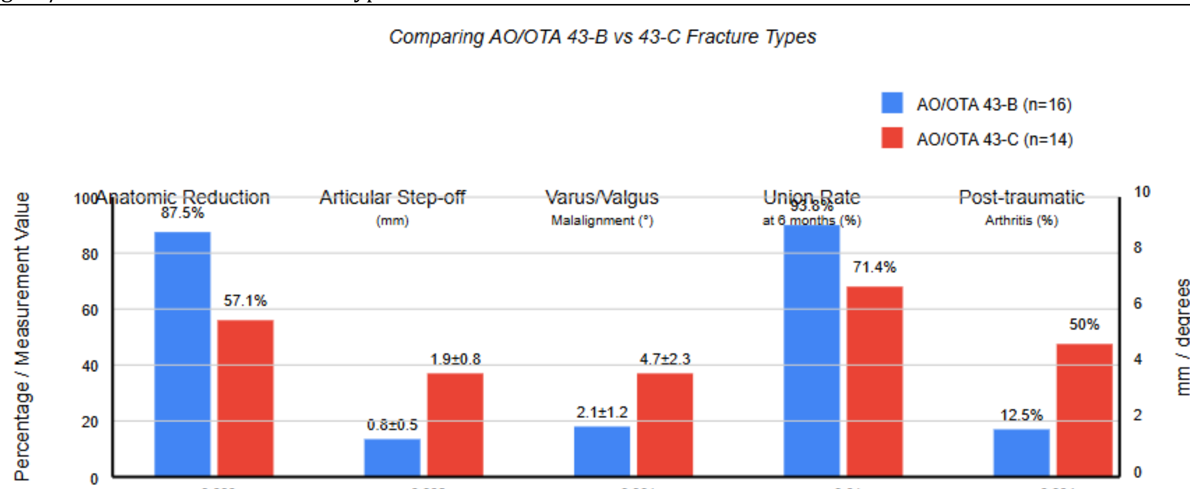
Postoperative Complications and Management

Complication Type	Incidence (n, %)	Management	Associated Factors*
Superficial Infection	3 (10%)	Antibiotics (oral)	Diabetes (OR 3.2, 95% CI: 1.4-5.8, p=0.01)
Deep Infection	1 (3.3%)	Surgical debridement, IV antibiotics	Extended surgical time (OR 2.8, 95% CI: 1.2-5.3, p=0.02)
Delayed Union	4 (13.3%)	Extended immobilization	AO type C3 (OR 4.5, 95% CI: 2.1-8.2, p=0.003) Smoking (OR 3.1, 95% CI: 1.5-6.4, p=0.01)
Malunion	2 (6.7%)	Corrective osteotomy (n=1)	Articular Step-off >2mm (OR 5.2, 95% CI: 2.4-9.8, p=0.001)
Hardware Irritation	5 (16.7%)	Hardware removal	Prominent locking plate (OR 2.1, 95% CI: 1.0-4.3, p=0.04)
Post-traumatic Arthritis	3 (10%)	NSAIDs, PT, IA injections	AO type C2/C3 (OR 6.8, 95% CI: 3.2-12.5, p<0.001) Articular Step-off >2mm (OR 7.5, 95% CI: 3.5-15.2, p<0.001)
Complex Regional Pain Syndrome	1 (3.3%)	Pain management, PT	Delayed rehabilitation (OR 3.7, 95% CI: 1.6-7.9, p=0.01)

**Based on multivariate logistic regression analysis*
PT = Physical Therapy, IA = Intra-articular, NSAIDs = non-steroidal anti-inflammatory drugs

Figure 2

Comparing AO/OTA 43-B vs 43-C Fracture Types



Bar graph illustrating radiographic outcomes between type B (n=16) and type C (n=14) tibial pilon fractures. Type B fractures show significantly better results across all parameters including higher anatomic reduction rates (87.5% vs 57.1%, p=0.008), smaller articular step-off (0.8±0.5mm vs 1.9±0.8mm, p=0.002), less varus/valgus malalignment (2.1±1.2° vs 4.7±2.3°, p=0.001), higher union rates at 6 months (93.8% vs 71.4%, p=0.01), and lower incidence of post-traumatic arthritis (12.5% vs 50%, p=0.004).

The comparison between radiographic outcomes of AO/OTA 43-B and 43-C fracture types demonstrated substantial differences in all evaluated parameters. The anatomic reduction success rates were higher in type B fractures compared to type C fractures at 87.5% vs 57.1% (p=0.008) and type B fractures showed less articular step-off at 0.8±0.5mm compared to type C fractures at 1.9±0.8mm (p=0.002). Type B fractures demonstrated significantly better varus/valgus alignment compared to type C fractures with measurements of 2.1±1.2° vs 4.7±2.3° (p=0.001). The 6-month union rates were superior in type B fractures at 93.8% compared to type C fractures at 71.4% (p=0.01) with significantly lower post-traumatic arthritis rates at 12.5% compared to 50% (p=0.004). These findings demonstrate the significant impact of fracture complexity on radiographic results after minimally invasive surgical intervention (Figure 2).

4. Discussion

The research examined both clinical results and radiological findings from minimal invasive surgical procedures used to treat tibial pilon fractures. The collected data shows minimal invasive techniques provide both safety and effectiveness for treating tibial pilon fractures. The results showed that functional and radiological outcomes became progressively worse with increasing fracture complexity. The study results demonstrate how the AO/OTA classification serves as a prognostic tool for surgical approach selection. The healing process and complication risk increase when patients have diabetes or smoke or experience soft tissue damage. Our research helps create appropriate treatment plans based on fracture types.

The demographic characteristics of tibial pilon fractures identified in our study are similar to those reported in the literature. The mean age of 45 ± 12 years and the male-to-female ratio of 1.5:1 are consistent with the mean age of 47.94 years and the male-to-female ratio of 2.2:1 reported by Lu et al. (2022). [7] The detection of high-energy trauma mechanisms in 67% of cases in our study is parallel to the total ratio of falls (64%) and traffic accidents (26%) reported in the study by Lu and colleagues. [7] The higher incidence of type B fractures (53%) compared to type C fractures (47%) according to the AO/OTA classification differs from the distribution reported by Lu and colleagues (43C [62%] and 43B [21%]).[7] This difference may be attributed to variations in the study populations and case selection criteria. When comorbidity factors were examined, our smoking rate (33%) was close to the rate reported by Lu and colleagues (37%).[7] The finding that diabetes increased the risk of superficial infection by 3.2 times in our study is consistent with the findings of Hu and colleagues (2022). [8] Hu and colleagues identified diabetes as a significant risk factor for surgical site infection (OR=3.196, 95% CI: 1.209-8.450) and found a significantly higher prevalence of diabetes in the infection group (17.91%) compared to the control group (4.29%). [8] Our hypertension rate (27%) is higher than the rates reported by Hu et al. in the infection group (13.43%) and the control group (7.14%), but no significant association between hypertension and infection was found in either study. [8] Our finding regarding the role of smoking in delayed union supports the view, mentioned in Morello and Gamulin's (2023) review, that smoking may be a risk factor for tibial fractures. [9] However, the lack of a significant effect on healing time in smokers in Lu et al.'s study indicates the need for further research with a larger sample size.[7]

The surgical duration of 70 ± 20 minutes achieved through minimally invasive surgical techniques in our study was shorter than the 110.6-minute duration recorded for the MIPO technique in Verma et al.'s (2023) study. [10] The shorter duration in our study could be explained by the combination of percutaneous fixation and MIPO technique and possible variations in patient case severity. The average intraoperative blood loss of 150 ± 40 mL in our study was lower than the 205.2 mL reported by Verma and colleagues for the MIPO group. [10] The most frequently used fixation techniques in our study were locked plates (60%) and cannulated screws (27%) which match the findings of Daniels and colleagues (2021) systematic review. [11] Daniels and colleagues compared ORIF (355 patients) and external fixation (57 patients) in open pilon fractures, demonstrating that both methods have their own advantages and disadvantages.[11] The intraoperative complication rate in our study was 20%, with the majority being minor complications (13%). The rates of superficial infection (4.3–14%) and wound complications (2–10%) in the review by Mair et al. (2021) [3] are comparable to our study's findings. The hospital stay duration of 5.8 ± 2.3 days in our study was significantly shorter than the 23.4-day duration reported by Verma and colleagues for the MIPO group. [10] This difference supports the efficacy of the minimally invasive techniques used in our study and, showing a significant difference according to the Rüedi-Allgöwer classification (p=0.01), indicates that fracture complexity affects hospital stay duration.

The average AOFAS score of 85 ± 8 obtained at 12 months in our study is similar to the average AOFAS score of 82.4 (range 62–94) reported by Gao and colleagues (2023) for AO/OTA C3 tibial pilon fractures. [12] This result suggests that minimally invasive methods can provide satisfactory functional outcomes even in complex pilon fractures. Additionally, the healing time ranging from 11 to 18 weeks according to the AO/OTA classification in our study is close to the average 3.38-month (approximately 13.5 weeks) healing time reported by Gao and colleagues. [12] The decrease in SF-36 physical component scores from 75 to 52 in our study according to fracture type is consistent with the average PCS value of 44.7 ± 8.9 reported by Ryan and colleagues (2025). [13] Ryan and colleagues reported that physical component scores in patients with pilon fractures were significantly lower than in the normal population (p ≤ 0.001).[13] Our return-to-work rate of 83% at 12 months is largely consistent with the 87% return-to-work rate reported by Ryan and colleagues (2025). [13] However, while Ryan and colleagues noted that 44% of those returning to work did so with reduced capacity, this proportion was not assessed in our study. In our study, age was identified as an important variable affecting AOFAS scores at 12 months (β=-0.32, p=0.008), but Bagherifard and colleagues (2023) found no significant association between age and functional outcomes in their study. [14] Bagherifard and colleagues reported that age did not correlate with the WOMAC score or its subscales (p > 0.05) and showed only a weak negative correlation with the pain subscale of the SF-36 (r = -0.255, p = 0.22). [14] This discrepancy may stem from differences in the study populations or the assessment scales used.

The radiological results from our study matched existing research findings about how AO/OTA fracture complexity affects anatomical reduction success rates. The decrease in the anatomical reduction rate from 87.5% in Type B fractures to 57.1% in Type C fractures indicates that fracture complexity significantly affects surgical outcomes. This finding, when compared to the 24.2% anatomical reduction rate reported by Zhan and colleagues (2025) in the traditional treatment group for AO/OTA type 43-C3 pilon fractures, demonstrates that our study achieved better results even for type C fractures. Our postoperative complication rate (63.3%) is higher than rates reported in the literature; however, most of these are minor complications. Our superficial infection rate (10%) is similar to the wound complication rates of 12–18% reported by Olson and colleagues (2021). [16] The research revealed that post-traumatic arthritis risk increases to 6.8 times in patients with AO type C2/C3 fractures because of both fracture complexity and reduction quality factors. The study results about smoking duration extending healing time (β=0.35, p=0.005) match the findings of Olson and colleagues (2021) who showed smoking increases deep infection risk by 2.4 times (OR 2.4, 95% CI: 1.3–4.6, p=0.008). [16] Resch and colleagues (2025) discovered that smokers with tibial plateau fractures had Tegner Activity Scores which were lower with a median of 2.5 and an IQR of 2–3. [17] The research by Olson and colleagues (2021) shows that diabetes causes healing time delays (β=0.30, p=0.01) and also increases deep infection risk by 2.6 times (OR 2.6, 95% CI: 0.9–7.3, p=0.063). [16] The healing potential of fractures shows a strong relationship with type B fractures achieving 93.8% union rates and type C fractures achieving 71.4% union rates at six months. This finding indicates that our study achieved higher healing rates compared to the high callus rates reported by Zhan and colleagues (2025) of 64.5% in the miniplate group and 30.3% in the traditional treatment group.

Our study has some limitations. The retrospective design introduces potential selection bias. The small number of participants in the study reduces the ability to detect differences between subgroups. The surgeon's preference for surgical techniques and the absence of randomization made it difficult to compare the two groups. The 24-month follow-up period restricted the assessment of extended complications. The standardised surgical protocol and detailed radiological and functional evaluations are the strengths of our study. Future studies should include larger patient groups, prospective and randomised designs, extended follow-up periods, and comparisons between different minimally invasive techniques. Further studies are needed to investigate the effects of implant selection on outcomes and the healing process when rehabilitation protocols are used.

5. Conclusion

The research shows that minimally invasive surgical methods represent a safe and effective treatment option for tibial pilon fractures. The complexity of fractures negatively impacts functional and radiological results yet proper patient selection and technical application leads to satisfactory outcomes. The AO/OTA classification system proves useful for both treatments planning and predicting patient outcomes. The anatomical reduction success rate together with complication frequency remains higher in Type B fractures than in Type C fractures which show increased risks of post-traumatic arthritis and non-union. The combination of diabetes and smoking with high body mass index leads to negative treatment outcomes in patients. The research demonstrates that minimal invasive surgical methods provide better operative benefits than traditional open surgery while reducing hospitalization duration. The treatment of tibial pilon fractures requires individualized approaches which consider both patient-specific factors and fracture characteristics.

Statement of ethics

This study was approved by the Ağrı Education and Research Hospital Ethics Committee (Decision No: 2018/347, Date: December 10, 2018).

genAI

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Conflict of interest statement

The authors declare that they have no conflict of interest.

Availability of data and materials

This Data and materials are available to the researchers.

Author contributions

Both authors contributed equally to the article. Both authors read and approved the final manuscript.

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