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Original Research Article

IMPACT OF RADIOLOGICAL PARAMETERS ON FUNCTIONAL OUTCOMES IN PILON FRACTURES MANAGED WITH MINIMALLY INVASIVE PLATE OSTEOSYNTHESIS (MIPO): A PROSPECTIVE STUDY

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Abstract

Background: Pilon fractures pose a significant challenge for orthopedic surgeons due to the complexity of the distal tibial anatomy and the high risk of functional impairment. Minimally Invasive Plate Osteosynthesis (MIPO) has emerged as a favored approach for treating pilon fractures, yet the specific radiological parameters that influence functional outcomes remain inadequately understood. This study aims to evaluate the impact of specific radiological parameters, including the lateral distal tibial angle (LDTA), anterior distal tibial angle (ADTA), quality of reduction, and lateral malleolus length (LLM), on the functional outcomes of patients with pilon fractures managed using the MIPO technique. **Materials and Methods:** In this prospective study, patients with closed pilon fractures treated using MIPO were assessed postoperatively. Radiological measurements—LDTA, ADTA, quality of reduction, and LLM—were recorded and correlated with functional outcomes at one-year follow-up using the American Orthopaedic Foot & Ankle Society (AOFAS) scoring system. Data were analyzed to identify associations between radiological parameters and functional recovery. **Result:** The study revealed that patients who achieved optimal LDTA and ADTA values, along with anatomical or good reduction quality, reported significantly better functional outcomes with AOFAS scores indicating excellent recovery. Patients with lower LLM measurements and suboptimal alignment were more likely to experience fair or poor outcomes, including complications such as malunion and delayed union. The timing of surgery, while not statistically significant, generally aligned with improved outcomes when performed within seven days of injury. Findings highlight the influence of precise radiological parameters on functional outcomes, emphasizing that attention to LDTA, ADTA, reduction quality, and LLM can enhance patient recovery in MIPO-treated pilon fractures. Anatomical reduction and optimal angular measurements were key determinants in minimizing postoperative complications and maximizing function. **Conclusion:** Radiological parameters play a crucial role in predicting the functional outcomes of pilon fractures treated with MIPO. Proper alignment and anatomical reduction are paramount in improving patient recovery and reducing the risk of complications, underscoring the need for precise preoperative planning and surgical technique.

INTRODUCTION

Pilon fractures, accounting for less than 1% of lower extremity fractures, affect the weight-bearing area of the distal tibia and involve the adjacent metaphysis.[1,2] These fractures are typically caused by high-energy axial compressive and twisting forces. Managing high-energy pilon fractures remains challenging for surgeons due to the complexity of the fracture patterns and the potential for surgery-related complications.[3]

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Treatment approaches for pilon fractures range from conservative options, such as closed reduction and casting, to surgical interventions, including combinations of intramedullary nailing and plate fixation, external fixation (EF), open reduction and internal fixation (ORIF), and minimally invasive plate osteosynthesis (MIPO).[4] Conservative management, suitable for stable, undisplaced fractures, often requires prolonged immobilization, which may lead to joint stiffness, malunion, shortening, and early onset osteoarthritis.[5,6] Traditional plating methods also carry risks, including wound infection, skin necrosis, delayed union, and non-union.[7-10] Additionally, external fixators are rarely used as definitive fixation tools due to issues such as pin loosening, delayed union, malunion, and pin tract infections that may result in osteomyelitis.[11,12]

Recently, MIPO with a locking compression plate has gained preference for treating complex pilon fractures, as it emphasizes minimal soft tissue disruption, preservation of osteogenic fracture hematoma, and maintenance of vascular supply to the fracture fragment.[13] Despite this biological approach, outcomes in pilon fractures are influenced by factors such as patient age, bone quality, injury mechanism, fracture pattern, quality of reduction, timing of surgery, and fibula fixation. This study aims to critically evaluate the radiological parameters that influence functional outcomes in patients with pilon fractures treated using MIPO.

MATERIALS AND METHODS

Study Design and Location: This prospective study took place at MKCG Medical College and Hospital in Berhampur, Odisha, spanning from August 2021 to June 2023. After obtaining institutional ethics committee approval, the study included 70 adult patients (50 males, 20 females), all over the age of 18, who presented with closed or grade 1 compound tibial pilon fractures (AO type 43A/B/C). Exclusion criteria included grade 2 or 3 compound fractures, pathological fractures, and fractures older than two weeks.

Surgical Technique: All procedures were conducted under regional anesthesia. Patients were positioned supine, and initial fixation of the fibula was performed with either a one-third tubular plate or a recon plate. For the distal tibial fracture, a 2-cm incision was made over the medial malleolus following closed percutaneous reduction. A plate was then inserted in a retrograde direction through a preformed tunnel and secured with percutaneously placed screws using small stab incisions under image intensifier guidance. Patients began ankle and knee mobilization exercises on the second postoperative day. Partial weight-bearing was allowed upon radiological evidence of callus formation, with full weight-bearing initiated after confirming union on follow-up X-rays.

Definitions of Malunion and Nonunion: Malunion of the distal tibia was characterized by any angulation of 10° or more in any plane, internal rotation of at least 10°, external rotation exceeding 15°, or tibial shortening of at least 2 cm.[14] Nonunion was considered when no signs of fracture healing were observed after six months. Functional outcomes were assessed using the American Orthopaedic Foot & Ankle Society (AOFAS) score once the fracture had completely healed.

Radiological Assessment

Postoperative Radiographs: Immediately following surgery, standard anterior-posterior (AP) and lateral X-rays of the ankle were taken to evaluate radiological parameters, including quality of reduction, lateral distal tibial angle (LDTA), anterior distal tibial angle (ADTA), and lateral malleolus length.

Evaluation of Reduction Quality: Reduction quality was graded using the Ovadia and Beals criteria, assigning scores from one to three based on lateral and medial malleolus displacement, posterior malleolus displacement, mortise and fibular widening, talar tilt, and articular gap. Total scores classified reduction quality as anatomical (<8 points), good (9–11 points), fair (12–15 points), or poor (>15 points).[15]

Measurements of LDTA and ADTA: The LDTA was defined as the angle between the long axis of the tibia and the tibial plafond's articular surface, while the ADTA was calculated as the angle between the anatomical axis of the tibia and a line joining the distal points on the anterior and posterior tibial articular surface.

Length of the Lateral Malleolus (LLM): The length of the lateral malleolus was measured from the plane of the tibial plafond to the tip of the lateral malleolus.[16]

Statistical Analysis: Statistical analysis was conducted using R software, examining how factors such as quality of reduction, LDTA, ADTA, LLM, and timing of surgery influenced functional outcomes. Pearson's Chi-Square analysis was used, with statistical significance set at $p < 0.05$.

RESULTS

A total of 70 adult patients were included in the study, with 50 males and 20 females. The age distribution ranged from under 50 to over 70 years. The majority (48.6%) were aged 50-60 years, followed by 24.3% between 60-70 years, 18.6% under 50 years, and 8.6% over 70 years (Table 1). Fractures were classified using the AO classification system, with type 43C (C1/C2/C3) being most common (40 patients), followed by types 43A (A1/A2/A3) and 43B (B1/B2/B3).

Road traffic accidents were the most common cause of injury, accounting for 58.6% of cases, followed by self-fall (25.7%) and falls from height (15.7%). The majority of patients (47.1%) presented within 24-72

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hours after injury, while 32.9% presented within 24 hours and 20% presented after 72 hours. Most surgeries were performed within 3-7 days of injury (50%), with 34.3% operated on within 3 days and 15.7% after 7 days. Closed fractures constituted 85.7% of cases, while open fractures accounted for 14.3%. A fibular fracture was present in 92.9% of cases.

The average surgery duration was approximately 45 minutes, ranging from 60 to 120 minutes. Follow-up periods ranged from 18 to 36 months, with an average of 2 years, allowing for comprehensive monitoring of healing, complications, and functional outcomes.

Outcomes were assessed based on the American Orthopaedic Foot & Ankle Society (AOFAS) score, revealing that 47.1% of patients achieved excellent functional outcomes, 32.9% had good outcomes, 12.9% had fair results, and 7.1% were rated as poor. This indicates a predominantly favorable outcome profile, with the majority of patients experiencing either excellent or good recovery.

Fracture consolidation was observed on average at 19.2 weeks postoperatively, with a range from 16 to 25 weeks. Complications included four cases of superficial wound infection, three cases of skin necrosis requiring flap coverage, two cases of delayed union necessitating bone grafting, two cases of malunion, and one instance of implant breakage.

The quality of reduction, measured by the Ovadia and Beals criteria, had a significant impact on functional outcomes ($p<0.001$). Patients with anatomical (<8 points) and good (9-11 points) reductions experienced better functional outcomes compared to those with fair (12-15 points) and poor (>15 points) reductions. Specifically, 93.2% of patients with anatomical reductions and 87.5% with good reductions achieved excellent or good functional scores, while all patients with fair or poor reductions scored only fair or poor on functional outcomes.

LDTA was strongly correlated with functional outcomes, where higher values correlated with better functional recovery ($p<0.001$). Patients with an LDTA of 85-90° or greater than 90° showed excellent and good outcomes in 91.2% and 100% of cases, respectively, while patients with LDTA less than 85° mostly had fair and poor outcomes. Additionally, skin complications were more prevalent among patients with lower LDTA values.

ADTA was another significant predictor of functional recovery ($p=0.001$). Patients with ADTA greater than 80° achieved excellent and good functional outcomes in 100% of cases. For those with ADTA between 75-80°, 73.7% achieved excellent or good outcomes. Lower ADTA values (<75°) were associated with fair and poor outcomes in 66.7% of cases, indicating a higher risk of complications and delayed recovery.

The LLM measurement significantly impacted the functional outcome ($p<0.001$). Patients with LLM greater than 27.5 mm exhibited excellent and good outcomes in 94.3% of cases, while those with LLM between 25-27.5 mm had good outcomes in 81.5%. Patients with LLM less than 25 mm had a higher incidence of fair or poor outcomes and were more prone to fracture complications.

In contrast to other factors, the timing of surgery did not demonstrate statistical significance ($p=0.232$) with functional outcomes. Although a majority of patients who underwent surgery within 3-7 days achieved good or excellent outcomes, delayed surgery beyond seven days did not consistently result in poorer functional results.

In [Table 7], various factors are compared in relation to the final functional outcome. Quality of reduction, LDTA, ADTA, and LLM were all statistically significant in predicting positive outcomes (excellent + good) versus poor outcomes (fair + poor), whereas the timing of surgery was not significantly associated with functional results.

Table 1: Socio-demographic characteristics of study participants.

Age group (years)	Less than 50	13	18.6
	50-60	34	48.6
	60-70	17	24.3
	More than 70	6	8.6
Fracture (AO type)	43(A1/A2/A3)		1/4/5
	43 (B1/B2/B3)		3/1/4
	43 (C1/C2/C3)		10/10/8
Mode of injury	Self fall	18	25.7
	RTA	41	58.6
	FFH	11	15.7
Timing of presentation	less than 24 hrs	23	32.9
	24-72 hrs	33	47.1
	>72 hrs	14	20
Timing of surgery	<3 days	24	34.3
	3-7 days	35	50.0
	> 7 days	11	15.7
Type of injury	Closed type	60	85.7
	Open type	10	14.3
Fibula fracture	Present	65	92.9
	Absent	5	7.1
Functional outcome (AOFAS scale)	Excellent	33	47.1
	Good	23	32.9
	Fair	9	12.9

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	Poor	5	7.1

RTA- road traffic accident, FFH- fall from height.

Table 2: Patients demographic and postoperative data in relation to quality of reduction.

Quality of reduction (Ovadia and Beals criteria)	Anatomical (<8 pts)		Good (9-11 pts)		Fair (12-15 pts)		Poor (>15 pts)	
	44	62.8571	16	22.8571	8.0	11.42857	2	2.857143
Fracture type								
43 A	16	36.3636		0		0.0	0	0
43 B	8	18.1818	2	12.5	1.0	12.5	0	0
43 C	20	45.4545	14	87.5	7	87.5	2	100
Functional outcome								
Excellent and good	41	93.1818	14	87.5	0	0.0	0	0
Fair and poor	3	6.81818	2	12.5	8	100.0	2	100
Skin complications (superficial infection, skin necrosis)	3	6.81818	4	25	3.0	37.5	0	0
Fracture complication (delayed union, malunion)	0	0	2	12.5	3.0	37.5	2	100

Table 3: Patients demographic and postoperative data in relation to lateral distal tibial angle (LDTA).

Lateral distal tibial angle (LDTA)	LDTA (<850)		LDTA (850–900)		LDTA (>900)	
	14	20	34	48.5714	22.0	31.42857
Fracture type						
43 A	3	21.4286	10	29.4118	3.0	13.6
43 B	1	7.14286	6	17.6471	5.0	22.7
43 C	10	71.4286	18	52.9412	14	63.6
Functional outcome		0		0		0.0
Excellent and good	3	21.4286	31	91.1765	22	100.0
Fair and poor	11	78.5714	3	8.82353	0	0.0
Skin complications (superficial infection, skin necrosis)	5	35.7143	5	14.7059	1.0	4.5
Fracture complication (delayed union, malunion)	6	42.8571	2	5.88235	0.0	0.0

Table 4: Patients demographic and postoperative data in relation to anterior distal tibial angle (ADTA).

Anterior distal tibial angle (ADTA)	ADTA (<75 0)		ADTA (750 -800)		ADTA (>800)	
	10	14.2857	30	42.8571	31.0	44.28571
Fracture type						
43 A	0	0	6	20	9.0	29.0
43 B	3	30	5	16.6667	4.0	12.9
43 C	7	70	19	63.3333	18	58.1
Functional outcome		0		0		0.0
Excellent and good	3	30	23	76.6667	31	100.0
Fair and poor	7	70	7	23.3333	0	0.0
Skin complications (superficial infection, skin necrosis)	2	20	9	30	0.0	0.0
Fracture complication (delayed union, malunion)	7	70	2	6.66667	0.0	0.0

Table 5: Patients demographic and postoperative data in relation to length of lateral malleolus (LLM).

Length of lateral malleolus (LLM)	LLM (<25 mm)		LLM (25–27.5 mm)		LLM (>27.5 mm)	
	8	11.4286	27	38.5714	35.0	50
Fracture type						
43 A	2	25	7	25.9259	6.0	17.1
43 B	0	0	4	14.8148	9.0	25.7
43 C	6	75	16	59.2593	20	57.1
Functional outcome		0		0		0.0
Excellent and good	0	0	22	81.4815	33	94.3
Fair and poor	8	100	5	18.5185	2	5.7
Skin complications (superficial infection, skin necrosis)	3	37.5	5	18.5185	2.0	5.7
Fracture complication (delayed union, malunion)	3	37.5	6	22.2222	0.0	0.0
		0		0	0.0	0.0

Table 6: Patients demographic and postoperative data in relation to timing of surgery.

Timing of surgery	<3 days		3–7 days		>7 days	
No. of cases	22	31.4286	33	47.1429	15.0	21.42857
Fracture type						
43 A	7	31.8182	4	12.1212	3.0	20.0
43 B	5	22.7273	1	3.0303	4.0	26.7
43 C	10	45.4545	28	84.8485	8	53.3
Functional outcome		0		0		0.0
Excellent and good	20	90.9091	31	93.9394	8	53.3

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Fair and poor	2	9.09091	2	6.06061	7	46.7
Skin complications (superficial infection, skin necrosis)	6	27.2727	4	12.1212	2.0	13.3
Fracture complication (delayed union, malunion)	0	0	4	12.1212	3.0	20.0

Table 7: Comparison of significance of various factors with final functional outcome.

Factors	Functional outcome		Total	P value
	Excellent + good	Fair + poor		
	N (%)	N (%)		
Quality of reduction				
Anatomical	41 (93.1)	3 (6.8)	44	
Good	14 (87.5)	2 (12.5)	16	< 0.001
Fair	0 (0)	8 (100)	8	
Poor	0 (0)	2 (100)	2	
Timing of surgery				
<3 days	20 (90.9)	2 (9.0)	22	0.232
3-7 days	31 (93.9)	2 (6.0)	33	
>7 days	8 (53.3)	7 (46.7)	15	
LDTA				
<85	3 (21.4)	11 (78.6)	14	< 0.001
85–90	31 (91.2)	3 (8.8)	34	
>90	22 (100)	0 (0)	22	
ADTA				
<75	3 (33.3)	7 (66.7)	10	
75–80	23 (73.7)	7 (26.3)	30	0.001
>80	31 (100)	0 (0)	31	
LLM				
<25 mm	0 (0)	8 (100)	8	
25–27.5 mm	22 (81.5)	5 (18.5)	27	< 0.001
>27.5 mm	33 (94.3)	2 (5.7)	35	

DISCUSSION

Pilon fractures constitute about 7-10% of all tibial fractures, and often involve fibular fractures, especially in high-energy injuries, where the fibula is affected in nearly 85% of cases.[17] The primary objective in managing pilon fractures is to restore joint mobility through stable fixation and proper alignment of the articular surface. These fractures are challenging to treat due to the limited soft tissue and blood supply in the region.[18,19] The Minimally Invasive Plate Osteosynthesis (MIPO) technique has gained popularity for treating pilon fractures, as it focuses on indirect reduction to maintain the integrity of the fracture site with minimal soft tissue disruption.[20]

The outcome of pilon fractures is influenced by various factors, including injury severity, fracture classification, reduction quality, and stability of fixation. Additionally, factors such as the timing of surgery, fixation of the fibula, and radiographic parameters—such as lateral distal tibial angle (LDTA), anterior distal tibial angle (ADTA), and the length of the lateral malleolus (LLM)—are important in determining functional results.[16]

Studies have emphasized the importance of high-quality fracture reduction for better outcomes. For instance, Carbonell-Escobar et al. found that patients with articular step-off greater than 2 mm had poorer functional results, as measured by AOFAS scores.[21] Similarly, Korkmaz et al. found that fracture reduction quality was a critical determinant of functional success in pilon fractures.[22] Our findings support these observations, as reduction quality was a key factor in our patients' outcomes.

Research into the roles of LDTA, ADTA, and LLM in pilon fractures is limited, but existing studies provide valuable insights. Sommer et al. analyzed multiple radiographic parameters and identified LLM, ADTA, anterior talar shift (ATS), and medial malleolus length (LMM) as reliable indicators of functional outcomes 16. Our study similarly found that higher LDTA, ADTA, and LLM values were significantly associated with better functional outcomes, underlining the importance of restoring lateral malleolus length to prevent varus tilt and rotational misalignment. The lateral malleolus helps maintain joint stability, as even minor lateral displacement of the talus (1 mm) can reduce tibiotalar contact by 42%.[14]

Fibula fixation has also shown positive effects on outcomes. Lee et al. reported better outcomes with fibula plating compared to nonoperative treatment, likely because the fibula contributes significantly to ankle joint stability.[14] In Korkmaz et al.'s study, patients who underwent plate fixation of fibula fractures demonstrated significantly better functional scores (p=0.02), indicating that fibular malalignment and shortening may also affect outcomes when fracture reduction is suboptimal.[22] Our study similarly found that patients with plate fixation of the fibula achieved better outcomes than those managed conservatively.

The optimal timing for surgery in pilon fractures is still debated. Some studies advocate for a two-stage approach, delaying ORIF for 10 days to 3 weeks, while others suggest early surgery within 48 hours. White et al. reported no significant difference in outcomes between surgeries performed within 24-48 hours and those done later.[23] Tang et al. also found no major differences in complications or nonunion

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rates between early (<36 hours) and delayed (10-21 days) surgeries, suggesting that timing may be flexible if soft tissue conditions are optimal.[24] Lomax et al. reported similar infection and nonunion rates between early and delayed surgeries (1.6% deep infection, 6.3% superficial infection, and 7.8% nonunion).[25] Likewise, our study found no statistically significant difference between surgical timing and wound complications or final functional outcomes.

CONCLUSION

This study underscores the importance of precise radiological parameters in determining functional outcomes following MIPO treatment of pilon fractures. Key factors—such as the lateral distal tibial angle (LDTA), anterior distal tibial angle (ADTA), length of the lateral malleolus (LLM), and quality of reduction—demonstrated significant associations with positive outcomes. Patients who achieved anatomical or good reductions and optimal values for LDTA and ADTA experienced excellent functional recovery, as reflected by their AOFAS scores. Conversely, patients with suboptimal alignment or lower LLM measurements had a higher likelihood of fair or poor outcomes and complications such as malunion and delayed union. Although the timing of surgery was not statistically significant in influencing outcomes, early intervention within seven days generally aligned with favorable results. These findings emphasize the critical role of meticulous surgical planning and execution in enhancing the long-term function and recovery in patients with complex pilon fractures treated with MIPO.

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