ORIGINAL ARTICLE

Two-Dimensional Radiological Analysis of Tibial Malalignment After Intramedullary Nailing: Prevalence, Associated Factors, and Outcomes

Che Mat Nasir MA[a], Ab Rahman S[a], Sharifudin MA[a,b,c], Ahmad MR[a], Ahmad NF[d]

[a]Department of Orthopaedics, School of Medical Sciences, Universiti Sains Malaysia, Malaysia
[b]Department of Orthopaedics and Rehabilitation, Faculty of Medicine, Universiti Sultan Zainal Abidin, Medical Campus, JalTerengganu, Malaysia
[c]Medical and Healthcare Research Cluster, Office of The Deputy Vice-Chancellor (Research and Innovation), Universiti Sultan Zainal Abidin, Terengganu, Malaysia
[d]Department of Radiology, Faculty of Medicine, Universiti Sultan Zainal Abidin, Medical Campus, Jalan Sultan Mahmud, Terengganu, Malaysia

ABSTRACT

INTRODUCTION: Tibial fractures are common long-bone fractures treated by orthopaedic surgeons. Intramedullary nailing (IMN) is the preferred standard treatment for tibial diaphysis fractures. This study aimed to evaluate the prevalence of tibial malalignment, its associated factors, and the outcomes following IMN. **MATERIALS AND METHODS:** A retrospective cross-sectional study was conducted on skeletally mature patients aged over 18 years who underwent IMN for tibial diaphysis fractures at a single academic trauma centre from January 2015 to December 2023. Data were extracted from the hospital database, including plain radiographs, medical records, and intraoperative notes. The Pearson chi-square test was used to examine the outcomes of malalignment, followed by logistic regression analyses to identify factors associated with tibial malalignment. **RESULTS:** A total of 163 patients were analysed. The prevalence of tibial malalignment following IMN was 66.0% in the proximal third, 58.8% in the distal third, and 25.0% in the middle third. The degree of comminution, specifically in Type 42C fractures, and lateral nail entry point were significantly associated with malalignment (p=0.02 and 0.011, respectively). However, no significant correlation was found between malalignment and bone union. **CONCLUSION:** Tibial malalignment is most common in the proximal third following IMN, with the degree of comminution being a significant factor. Despite the high prevalence of malalignment, it did not adversely affect bone union. These insights can guide preoperative planning and intraoperative techniques to optimize patient outcomes in tibial diaphysis fractures.

Keywords
tibial diaphyseal fractures, bone union, comminuted fractures, malalignment of tibia, intramedullary nailing.

Corresponding Author
Assoc. Prof. Dr Shaifuzain Ab Rahman
Department of Orthopaedics, School of Medical Sciences, Universiti Sains Malaysia
Email: shaifuzain@usm.my

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INTRODUCTION

Tibia diaphysis fractures are among the most prevalent long bone injuries encountered by orthopaedic surgeons, often resulting from high-impact trauma such as road traffic accidents or direct blows.[1,2] These fractures are classified into three segments: proximal, middle, and distal thirds. Diagnosis generally involves plain radiographs of the tibia and adjacent joints. Treatment options vary based on fracture configuration, soft tissue condition, and surgeon preference, including braces, external fixation, plate fixation, and intramedullary nailing (IMN). Each technique has specific indications, complications, and varying union rates.[1,3,4]

IMN is often the preferred method for managing tibial diaphysis fractures due to its load-sharing properties, high union rates, reduced soft tissue damage, lower infection risks, and shorter immobilization periods that facilitate early weight-bearing.[2,3,5-8] The primary goals of IMN are

to achieve a stable construction, ensure good fracture reduction, and maintain proper sagittal and coronal alignment, as well as restore rotation and length.[9] Despite these advantages, optimizing alignment and stability during IMN remains contentious.[2-4,10,11]

A significant complication of IMN is malalignment, which can lead to angular deformities such as varus, valgus, recurvatum, and procurvatum. Malalignment is defined as an angular deformity exceeding 5 degrees in any plane.[11,12] Malalignment in the tibia is defined by varus-valgus angulation exceeding 5 degrees, anterior/posterior angulation or rotational malalignment exceeding 10 degrees, less than 50% cortical apposition, or more than 1 cm of shortening.[7] Studies have reported its prevalence after IMN to range from 30% to 80%, with earlier literature cautioning against IMN for proximal third diaphyseal fractures due to the increased risk of deformity.[2] Contributing factors include deforming forces from surrounding musculature and inadequate endosteal fit of the nail.[4,6,13]

Despite the known prevalence of tibial malalignment, comprehensive data on its incidence across different tibial segments and the factors influencing these outcomes are lacking. This study aims to evaluate the prevalence of tibial malalignment in the proximal, middle, and distal thirds of the tibia, identify factors leading to angular deformities, and assess their impact on bone union. By providing this data, the research seeks to assist surgeons in preoperative planning and intraoperative decision-making, minimizing complications and enhancing patient quality of life.

MATERIALS AND METHODS

This single-centre, retrospective cross-sectional study was conducted at an academic trauma centre and commenced after obtaining ethical approval from the institution's Human Research Ethics Committee (Ref.: USM/JEPeM/KK/23060435). The study included patients over 18 years of age or those who had reached skeletal maturity, all of whom were admitted for tibial diaphysis fractures requiring surgical fixation with IMN between January 2015 and December 2023. Patients who were treated non-operatively, had received fixations other than IMN, had intra-articular fractures, congenital anomalies such as fibular hemimelia, or had poor-quality preoperative or postoperative radiographs that did not yield helpful information were excluded from the study. Data was collected from the centre's electronic database, medical records, and intraoperative notes. No patients were directly recruited for participation in this study.

Demographic, injury, and treatment data were extracted from medical records and intraoperative notes. Numerical and radiological findings (plain radiographs) in both coronal and sagittal views were measured using the Universal Viewer Zero Footprint Client (PACSZFP3 system). Tibial diaphysis fractures were classified based on their location into proximal, middle, and distal thirds (Figure 1). The longitudinal length of the tibia was measured using PACSZFP3 software, dividing it into three equal segments to determine the precise fracture location.

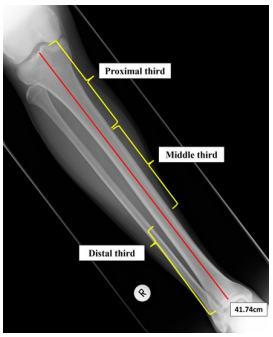

Figure 1: Location of fracture site along the tibial diaphysis, categorized into the proximal, middle, and distal thirds. The total length of the tibial diaphysis is measured (indicated by the red longitudinal line: 41.74 cm) and equally divided into three segments to determine the fracture location.

In the anteroposterior (AP) view, malalignment was evaluated using the anatomical axis as a reference point. A vertical line was drawn from the midpoint of the tibial spines to the distal end of the tibia, just above the tibiotalar joint (Figure 2). Any deviation from this line was categorized as malalignment, either in varus or valgus, and the angle of deviation was measured using the PACSZFP3 system. For the lateral radiograph, the anatomical axis was defined as a line passing through the medullary canal, positioned 7 cm from the plateau and 7 cm from the plafond (Figure 3).[14] Deviations from this axis were categorized as malalignment, either in procurvatum or recurvatum, with angles also measured

using the PACSZFP3 system. Significant malalignment was defined as any deviation exceeding 5 degrees on the AP radiograph and any deviation exceeding 10 degrees on the lateral radiograph.

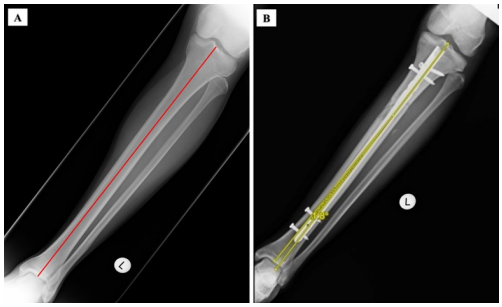

Figure 2: Anatomical axis of the tibia on anteroposterior view plain radiographs. The axis is drawn from the midpoint of the tibial spines to the distal end of the tibia, as depicted by **(A)** the red line on a normal tibia and **(B)** the yellow line on a tibia with a post-intramedullary nail (IMN), indicating a minimal valgus malalignment of 1.8 degrees.

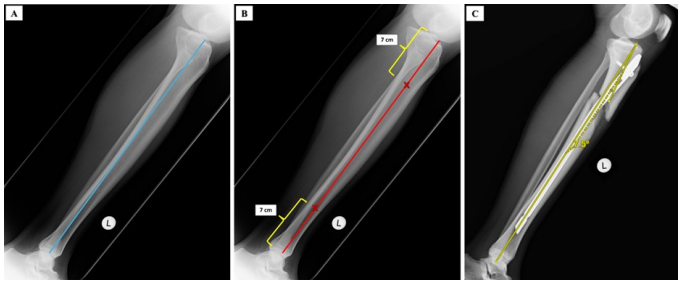

Figure 3: Lateral view plain radiographs of the tibia. **(A)** Represents the mechanical axis (blue longitudinal line), **(B)** shows the anatomical axis (red longitudinal line), determined by a line passing through the medullary canal, positioned 7 cm from the plateau and 7 cm from the plafond, and **(C)** depicts a 7.5-degree procurvatum malalignment of a proximal third tibial fracture post-intramedullary nail (IMN), as indicated by the yellow line.

The degree of comminution in tibial diaphysis fractures was evaluated using plain radiographs based on the Arbeitsgemeinschaft für Osteosynthesefragen/ Orthopaedic Trauma Association (AO/ OTA) classification system. Type 42A includes simple fractures with no significant comminution, which may be transverse, oblique, or spiral in nature. Type 42B is characterized by moderate comminution, where multiple fragments are present, but the fracture still maintains some degree of stability. Type 42C represents highly comminuted fractures with multiple fragments and instability, typically resulting from high-energy trauma.

Information regarding the size and type of nail used, as well as the grade of open fractures according to the Gustilo-Anderson classification, was retrieved from intraoperative notes. The presence and location of fibular fractures were analysed using both plain radiographs and intraoperative records. Any discrepancies identified in the radiological findings, intraoperative notes, or medical records were addressed based on current concepts and literature related to the management of tibial diaphysis fractures.

Outcomes related to tibial malalignment were assessed using plain radiographs obtained during the postoperative follow-up period. Radiographic images were reviewed to evaluate the progress of bone union within six months following the surgical procedure. The absence of at least three cortical bridges beyond this timeframe indicated non-union or delayed union.

The collected data was analysed using IBM SPSS version 27. Descriptive statistics summarized the sociodemographic characteristics of the patients, with numerical data presented as mean and standard deviation (SD) or median and interquartile range (IQR). Categorical data were reported as frequency and percentage. Factors associated with tibial malalignment were determined using logistic regression analysis, while crosstabulation (Pearson chi-square) was utilized to examine the outcomes of malalignment, followed by simple and multiple logistic regression analyses to assess associated factors following IMN.

RESULTS

A total of 163 patients were identified and analysed. The mean age of the entire cohort was 32.61 years (SD=16.57), with 122 patients (74.8%) being male. Most patients (n=142, 87.1%) sustained their injuries from motor vehicle accidents (MVA), while 21 patients (12.9%) experienced injuries due to non-MVA trauma. Table I shows the distribution of coronal and sagittal alignment based on the location of the tibial diaphysis. Regarding coronal alignment, the most significant malalignment cases were found in the proximal third of the tibial diaphysis, affecting six patients (66.7%). This was followed by malalignment in the distal third, which affected 40 patients (58.8%), and in the middle third, which affected 22 patients (25.6%). The analysis of sagittal alignment revealed that 44.4% of proximal third fractures (n = 4) exhibited malalignment, while the distal third showed a malalignment rate of 13.2% (n=9), and the middle third had a rate of 1.2% (n=1).

Table I: Prevalence and degree of malalignment by tibial diaphyseal location.

Degree of malalignment	Proximal third n (%)	Middle third n (%)	Distal third n (%)
Coronal plane			
< 5° varus	2 (22.2)	28 (32.6)	15 (22.1)
> 5° varus	3 (33.3)	11 (12.8)	17 (25.0)
< 5° valgus	1 (11.1)	36 (41.9)	13 (19.1)
> 5° valgus	3 (33.3)	11 (12.8)	23 (33.8)
Total cases of significant coronal malalignment	6 (66.7)	22 (25.6)	40 (58.8)
Sagittal plane			
< 5° procurvatum	3 (33.3)	45 (52.3)	22 (32.4)
> 5° procurvatum	4 (44.4)	0 (0.0)	2 (2.9)
< 5° recurvatum	2 (22.2)	40 (46.5)	37 (54.4)
> 5° recurvatum	0 (0.0)	1 (1.2)	7 (10.3)
Total cases of significant sagittal malalignment	4 (44.4)	1 (1.2)	9 (13.2)

Table II shows the association between tibial alignment and bone union among the 163 patients with tibial diaphysis fractures. There was no significant association between alignment groups and bone union (p>0.05). Specifically, 55 patients (72.4%) with varus malalignment achieved bone union, compared to 72 (82.8%) with valgus malalignment. For sagittal malalignment, 57 patients (75.0%) with procurvatum and 70 patients (80.5%) with recurvatum experienced bone union.

Table II: Association of tibial alignment and bone union outcomes (n = 163)

Tibial alignment		Bone union n (%)	Non-union/ Delayed union n (%)	p value*
Coronal plane				0.111
	Varus	55 (72.4)	21 (27.6)	
	Valgus	72 (82.8)	15 (17.2)	
	Total	127 (77.9)	36 (22.1)	
Sagittal plane				0.402
	Procurvatum	57 (75.0)	19 (25.0)	
	Recurvatum	70 (80.5)	17 (19.5)	
	Total	127 (77.9)	36 (22.1)	

*Pearson chi-square applied

Table III presents descriptive statistics related to tibial malalignment. The highest percentage of malalignment was observed among patients with Type 42C fractures, with 12 out of 14 patients (85.7%) affected. Nearly half of the patients with Grade 1 and Grade 2 open fractures also exhibited tibial malalignment. Similarly, almost half of the patients with concomitant fibular fractures (46.0%) had tibial malalignment, with the highest prevalence found in proximal fibular fractures, affecting 18 out of 30 patients (60%). This was followed by the same-level fibular fractures at 43.4% and distal fibular fractures at 38.7%. Among the nail entry points, lateral entry had the highest malalignment rate, with 10 out of 12 patients (83.3%) affected. The analysis of nail size revealed that sizes 9 to 11 were the most used, showing nearly equal prevalence of tibial malalignment among patients with sizes 9 and 10. Although the highest percentage of malalignment was observed in patients with nail size 8 (100.0%) and size 12 (66.7%), these groups had the fewest patients, indicating a potential skew in the results.

Table III: Descriptive statistics of factors associated with tibial malalignment

Variable	Total, n	Presence of tibial malalignment	
		YES, n (%)	NO, n (%)
Degree of comminution (OA/OTA Classification)			
Type 42A	94	32 (34.0)	62 (66.0)
Type 42B	55	28 (50.9)	27 (49.1)
Type 42C	14	12 (85.7)	2 (14.3)
Open fracture (Gustilo Anderson Classification)			
Grade 1	96	46 (47.9)	50 (52.1)
Grade 2	12	6 (50.0)	6 (50.0)
Grade 3	18	3 (16.6)	15 (83.3)
Concomitant fibular fracture			
Yes	137	63 (46.0)	74 (54.0)
No	26	9 (34.6)	17 (65.4)
Location of concomitant fibular fracture			
Proximal	30	18 (60.0)	12 (40.0)
Same level	76	33 (43.4)	43 (56.6)
Distal	31	12 (38.7)	19 (16.3)
Site of nail entry			
Medial	8	5 (62.5)	3 (37.5)
Center	143	57 (39.9)	86 (60.1)
Lateral	12	10 (83.3)	2 (16.7)
Size of nail (mm)			
8	1	1 (100.0)	0 (0.0)
9	16	8 (50.0)	8 (50.0)
10	74	35 (47.3)	39 (52.7)
11	69	26 (37.7)	43 (62.3)
12	3	2 (66.7)	1 (33.3)

The results of simple logistic regression, shown in Table IV, identified factors associated with tibial malalignment, including the degree of comminution, Gustilo-Anderson classification, presence of fibular fractures, location of fibular fractures, entry point of the nail, and nail size. The degree of comminution (Type 42C fractures) and lateral nail entry point showed statistically significant associations with malalignment (p=0.02 and p=0.011, respectively). A multiple logistic regression analysis included all variables with a p<0.25 and those deemed clinically important from simple logistic regression. The final model indicated that the degree of comminution, classified by AO/OTA, was significantly associated with tibial malalignment. Specifically, patients with Type 42C fractures were 17 times more likely to experience malalignment compared to those with Type 42A fractures (Adjusted OR=2.730; 95% CI:1.832, 159.802; p=0.013).

DISCUSSION:

Tibial diaphysis fractures are common in orthopaedic practice, and this study aimed to evaluate tibial malalignment following IMN, along with its contributing factors and effect on bone union. Despite IMN's high union rates and clinical efficacy, managing fractures,

particularly in the proximal and distal thirds, remains challenging.[3,4,13] Our findings align with previous studies, indicating that malalignment was most prevalent in the proximal third of the tibia (66%), observed in both sagittal and coronal planes, within the reported range of 44% to 84%.[7,11]

Table IV: Simple and multiple logistic regression analysis of factors associated with tibial malalignment

Variables	SLR[a]		MLR[b]	
	Crude OR (95% CI)	p value	Adjusted OR (95% CI)	p value
Degree of comminution (OA/OTA)				
Type 42A	1		1	
Type 42B	2.009 (1.019, 3.963)	0.044	1.222 (0.387, 3.859)	0.732
Type 42C	11.625 (2.451, 55.131)	0.002	17.111 (1.832, 159.802)	0.013
Open fracture (Gustilo Anderson)				
Grade 1	1			
Grade 2	0.200 (0.037, 1.071)	0.060		
Grade 3	0.850 (0.231, 3.129)	0.807		
Concomitant fibular fracture				
No	1			
Yes	1.608 (0.670, 3.858)	0.287		
Location of concomitant fibular fracture				
Distal	1			
Proximal	2.375 (0.850, 6.636)	0.099		
Same level	1.215 (0.518, 2.852)	0.654		
Site of nail entry				
Centre	1			
Medial	2.515 (0.578, 10.936)	0.219		
Lateral	7.544 (1.594, 35.708)	0.011		
Size of nail	0.771 (0.496, 1.199)	0.249		

[a]Simple logistic regression applied.
[b]Forward stepwise multiple logistic regression model applied. The model's overall fit was checked and reported to be the Hosmer and Lemeshow Test (p>0.95), overall, correctly classified percentage = 71.4%, and the area under the curve (63.9%) was applied to check the model's fitness.
CI: confidence interval, MLR: multiple logistic regression, OR: odds ratio, SLR: simple logistic regression.

Managing proximal tibial fractures with IMN is challenging due to the tibia's voluminous shape and its proximity to the knee joint, which complicates nail insertion and increases the bending moment on the proximal fragment.[13,15] The distal Herzog bend in standard IMNs can cause displacement of the distal segment during insertion, contributing to malalignment.[16] Studies have linked proximal third fractures to higher incidences of malalignment in both sagittal and coronal planes.[8,11,15,16] Although modern IMNs feature a more proximally positioned Herzog bend to improve interlocking, correct nail positioning remains crucial to prevent malalignment.

Proper nail positioning is crucial for distal tibial fractures,[3,4,15] where malalignment was more common in the coronal plane (58.8%) than in the sagittal plane (13.2%). Studies show that distal nail placement, lateral to the talus and plafond or along the tibial mechanical axis, reduces coronal plane malalignment compared to medial placement, with malalignment rates of 2.9% versus 27.5%, respectively.[17] In the sagittal plane, malalignment reached 48%, with the highest incidence occurring in the anterior quadrant (100%).

The study found that the degree of comminution significantly affected tibial malalignment, with Type 42C fractures showing a 17-fold higher risk than Type 42A fractures. Previous studies have also linked comminuted fractures to malalignment following IMN,[2,10] 58% of tibial malalignments following IMN were associated with segmental or comminuted fractures, emphasising the importance of employing pre-reduction techniques to achieve proper alignment before nail insertion.[11] Previous studies have also linked comminuted fractures to malalignment following IMN, with 58% of tibial malalignments associated with segmental or comminuted fractures. This emphasises the importance of pre-reduction techniques,[4,15] such as large distractors, external fixators, or direct reduction methods, to realign bone fragments and optimize fracture healing before nail insertion.[9]

The tibial anatomy and nail curvature influence the entry point for IMN. For proximal tibial fractures, the ideal entry is behind the patellar tendon, either via a flexed knee or suprapatellar approach.[9,18] This central alignment with the tibial spine and medullary canal reduces pressure on the fracture, aiding reduction and minimizing fluoroscopy time. The optimal starting point should be central, in line with the medial to lateral tibial spine and the medullary canal.[19] Using the suprapatellar approach allows for nail insertion without exerting pressure on the reduced fracture fragments, facilitating easier reduction and minimizing the duration of intraoperative fluoroscopy.[18] Although some studies report no significant differences in outcomes between suprapatellar, infrapatellar, or lateral approaches, proper alignment with the medullary canal remains crucial to prevent malalignment.[20] Additionally, proximal locking improves

implant stability.[5]

The study did not reach statistical significance due to the small sample size; however, other research suggests that the nail entry point influences the degree of malalignment. Lateral entry points often cause varus deformity, while medial entry points lead to valgus malalignment.[21] Our study supports this, showing a significant correlation between the entry point and posterior alignment, with over 80% of lateral entries resulting in malalignment. Another study suggested that the ideal entry point for IMN should be centrally located, noting that 25% of fractures with a medial entry point showed no deviation, while all fractures with a lateral entry point exhibited some degree of misalignment.[14]

Open fractures classified by the Gustilo-Anderson system present challenges due to soft tissue injuries and infection risks. However, our study found no significant correlation between injury grade and malalignment prevalence, suggesting that this classification primarily assesses soft tissue severity and may not fully capture the complexities of malalignment in tibial fractures.

Fibular fractures often accompany tibial fractures due to their anatomical proximity. In this study, we found no significant correlation between fibular fractures and tibial malalignment. Previous research has shown mixed results regarding the impact of fibular fixation on malalignment rates.[1,9] Some studies reported minimal occurrences of malunion and malalignment without fibular fixation.[12,22] In contrast, others indicated that fixing the fibula alongside IMN reduces tibial malalignment and ankle malrotation in distal third fractures.[10] One study indicated that malalignment prevalence is higher in cases of fibular fractures, with rates of 8.3% in intact fibulas compared to 21.8% in fractured fibulas.[23] However, recent studies have found no significant relationship between fibular fixation and tibial non-union rates.[1,24,25] Our findings suggest that the presence of a fibular fracture does not inherently increase the risk of malalignment in tibial diaphysis fractures treated with IMN.

Our study found no significant correlation between nail size and malalignment incidence, supporting literature that suggests nail size should be determined by the intramedullary canal dimensions. Over-reaming can facilitate insertion and reduce hoop stress. Current research indicates no differences in union rates based on nail size, and larger nails may pose additional risks. Conversely, smaller nails simplify procedures, reduce costs, and minimize blood loss.[26] Some studies recommend reserving larger diameter IMN for revision surgeries.[27] Ultimately, factors influencing nail insertion may be more critical than nail size itself, with the choice of nail size prioritizing optimal surgical outcomes and minimized risks.

Tibial malalignment can significantly impact bone union and healing, potentially leading to complications like delayed union or non-union due to improper load distribution and inadequate stabilization. Malalignment disrupts optimal healing conditions, including fracture stabilization and mechanical loading. However, our study found no significant impact on non-union or delayed union rates, likely due to effective fracture stabilization and sufficient intraosseous stimulation through IMN.[28] Similar findings have been reported in previous studies, indicating that malalignment is not independently associated with non-union.[29]

LIMITATIONS

This study has several limitations. The retrospective cross-sectional design and relatively small sample size limit causal inference and reduce statistical power, making it difficult to detect subtle differences among fracture subgroups. Reliance on existing radiographs and medical records led to inconsistent or incomplete clinical outcome data, particularly regarding functional impairment and rotational malalignment. Additionally, rotational deformities were not assessed due to the inherent limitations of two-dimensional radiographs, which are less accurate than advanced imaging or clinical evaluation for detecting such deformities. Variability in IMN implant types and the limited representation of medial and lateral nail entry points further constrain the generalisability of our findings, as different surgical approaches may influence outcomes differently.

FUTURE RECOMMENDATIONS

Future research should focus on prospective, multicentre studies with larger cohorts to improve statistical power and reduce bias. Standardised surgical protocols combined with advanced imaging techniques, such as computed tomography, and thorough clinical rotational assessments will enable a more comprehensive evaluation of tibial malalignment, including rotational deformities that significantly impact patient function. Incorporating systematic collection of patient-reported outcomes and functional assessments is essential to link radiographic findings with clinical relevance. Further investigation of intraoperative techniques, including optimal nail entry point selection, use of blocking screws, and effective pre-reduction methods, could enhance surgical precision and reduce malalignment risk. These efforts will contribute to evidence-based protocols that optimise alignment and improve patient outcomes following IMN of tibial diaphysis fractures.

CONCLUSION

This study confirms the effectiveness of IMN as the preferred treatment for tibial diaphysis fractures, demonstrating favourable outcomes in bone union and minimal complications. Although malalignment remains a common issue, particularly in proximal and comminuted fractures, careful preoperative planning and precise surgical techniques can enhance patient outcomes. Key strategies to minimize angular deformity include adequate imaging, optimal entry point selection, and maintaining proper reduction throughout the procedure. By prioritizing these practices, surgeons can improve the success of IMN treatment for tibial diaphysis fractures.

INSTITUTIONAL REVIEW BOARD (ETHICS COMMITTEE)

This single-centre, retrospective cross-sectional study was conducted at an academic trauma centre and commenced after obtaining ethical approval from the institution's Human Research Ethics Committee (Ref.: USM/JEPeM/KK/23060435).

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