Systematic Review

MALALIGNMENT AFTER TIBIAL SHAFT FRACTURE FIXATION: MECHANISMS, RISK FACTORS, ASSESSMENT, AND PREVENTION :A SYSTEMATIC REVIEW

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ABSTRACT

Background: Tibial shaft fractures are the most common long-bone fractures, and surgical fixation aims to restore anatomical alignment to optimize biomechanical loading and facilitate union. Iatrogenic malalignment remains a significant complication, particularly in fractures involving the metaphyseal flare (proximal or distal thirds). This review synthesizes current evidence on the mechanisms, risk factors, modern assessment techniques, and preventive strategies for malalignment following tibial shaft fracture fixation.

Materials and Methods: A narrative systematic review of the literature was conducted utilizing electronic databases (PubMed, EMBASE, Cochrane) with PRISMA guidelines .Priority was given to recent studies published between 2020 and 2025, supported by seminal foundational papers. Studies evaluating intramedullary nailing (IMN), plate osteosynthesis, and external fixation were included.

Results: Malalignment acts as a critical independent predictor of nonunion and long-term joint degeneration. Commonly accepted thresholds for unacceptable malalignment include >5° in the coronal plane, >5-10° in the sagittal plane, >10-15° of rotation, and >1-2 cm of shortening. Recent cohorts report distal fracture coronal/sagittal malalignment rates around 13%. Furthermore, computed tomography (CT)-based studies reveal that rotational malalignment affects approximately 30% of patients, frequently unrecognized on standard radiographs. Preventative strategies, such as multiplanar distal interlocking and the use of poller (blocking) screws, demonstrate robust efficacy in minimizing deformity. While the suprapatellar approach improves intraoperative positioning and sagittal reduction, recent data suggests it does not significantly reduce the incidence of CT-defined rotational malalignment compared to infrapatellar approaches.

Conclusion: Precise surgical planning, utilization of adjunctive reduction tools (e.g., blocking screws), and advanced assessment modalities (e.g., postoperative CT for rotational profiling) are essential to mitigate the risk of malalignment. Clinicians must address specific plane-dependent deforming forces to minimize mechanical complications and improve patient outcomes.

Keywords: Tibial shaft fracture; Intramedullary nailing; Malalignment; Malunion; Poller screws; Rotational deformity.

INTRODUCTION

Tibial shaft fractures represent the most frequently encountered long-bone fractures in orthopaedic trauma. The superficial anatomical location of the tibia renders it highly susceptible to both high-energy traumatic forces and low-energy torsional injuries. The primary objective of surgical intervention—whether by intramedullary nailing (IMN), minimally invasive percutaneous plate osteosynthesis (MIPPO), or external fixation—is to restore the mechanical axis, length, and rotation of the lower extremity while preserving the local soft-tissue envelope.[1,2] Despite advances in implant design and surgical technique, post-operative malalignment remains a persistent challenge that is biomechanically significant. Malalignment shifts load-bearing forces across the adjacent knee and ankle joints, independently predicts delayed union or nonunion, and contributes to early-onset secondary osteoarthritis.[3-5]

Fractures localized to the proximal and distal thirds of the tibial shaft carry the highest risk of malalignment due to the discrepancy between the narrow diaphyseal canal and the widened metaphyseal flare, colloquially known as "canal mismatch," combined with asymmetric muscular deforming forces.[6] This narrative review aims to comprehensively evaluate the mechanisms contributing to malalignment, delineate the accepted radiographic thresholds, discuss the role of modern assessment modalities like computed tomography (CT), and highlight contemporary surgical strategies to prevent postoperative deformity.

Review Methodology

A narrative systematic review of the literature was conducted by searching PubMed, EMBASE, and the Cochrane Library for articles published from 1990 to 2025 using PRISMA guidelines with a strong emphasis on recent studies published between 2020 and 2025. Search terms included "tibial shaft fracture", "malalignment", "malunion", "intramedullary nailing", "poller screws", "suprapatellar approach", and "rotational deformity". Studies that reported on radiographic outcomes, CT-based rotational assessments, biomechanical consequences, and surgical reduction techniques were selected for inclusion. Seminal historical papers were retained to provide context on foundational principles of tibial fracture management.

Definitions and Thresholds of Malalignment

Establishing standardized thresholds for acceptable tibial alignment is critical for both intraoperative decision-making and postoperative evaluation. While minor deviations from anatomical alignment are generally well-tolerated, deformities exceeding specific parameters lead to altered joint contact pressures and impaired gait mechanics. [Table 1] summarizes the widely accepted clinical guides for acceptable tibial alignment limits.[7-9]

Table 1: Commonly Used Thresholds for Unacceptable Tibial Malalignment

Anatomical Plane	Deformity Pattern	Unacceptable Threshold	Biomechanical Consequence
Coronal	Varus / Valgus	> 5°	Altered load distribution; medial (varus) or lateral (valgus) compartment knee osteoarthritis.
Sagittal	Procurvatum / Recurvatum	> 5° to 10°	Altered knee kinematics; anterior knee pain; compensatory joint hyper-extension.
Axial (Rotational)	Internal / External Torsion	> 10° to 15°	Gait disturbance; external rotation is generally better tolerated than internal rotation.
Translational	Shortening	> 1.0 to 2.0 cm	Leg length discrepancy; pelvic obliquity; secondary spinal pathology.

It is important to acknowledge variability across studies regarding these exact cutoffs. For example, while 5° is standard for coronal deformity, some older studies permit up to 10° before classifying it as a clinical malunion. However, modern stringent standards increasingly favor strict adherence to the <5° threshold in all planes to minimize long-term arthrosis.[8]

Plane-Specific Patterns of Deformity

Coronal Plane: Varus and Valgus

Coronal malalignment most frequently presents as valgus deformity in proximal-third fractures and varus deformity in distal-third fractures. In the proximal tibia, the asymmetrical pull of the lateral extensor musculature (anterior tibialis, extensor digitorum longus) combined with the lack of opposing medial forces naturally draws the proximal fragment into valgus.[10] Conversely, distal fractures often drift into varus, especially if the fibula is intact, acting as a lateral strut that prevents the distal fragment from aligning centrally.[11]

Sagittal Plane: Procurvatum and Recurvatum

Procurvatum (apex anterior) is the most common sagittal plane deformity, predominantly affecting proximal tibial fractures. The extensor mechanism (patellar tendon) forcefully pulls the short proximal fragment into extension. During conventional infrapatellar (IP) nailing, the necessary knee flexion further exacerbates this extensor pull, while a posteriorly directed nail starting point drives the distal segment posteriorly, locking the fracture in procurvatum.[6,12]

Axial Plane: Rotational Malalignment

Axial malalignment (torsion) is a frequent yet historically under-recognized complication. Because cylindrical tibial shaft fractures provide no inherent rotational keying, establishing rotation relies entirely on surgical judgment. Internal rotation deformities are generally poorly tolerated as they cause an in-toeing gait that leads to frequent tripping, whereas minor external rotation closely mimics the natural foot progression angle and is better tolerated.[13]

Mechanisms by Fixation Method

Intramedullary Nailing (IMN)

IMN is the gold standard for diaphyseal fractures, but it poses distinct challenges in the metaphyseal zones. The "canal mismatch" allows the nail to toggle within the wide cancellous metaphysis. If the entry point is slightly eccentric, the rigid nail will act as a deforming lever arm as it enters the narrow diaphysis. For instance, a starting point that is too medial on the proximal tibia will predictably force the proximal fragment into valgus as the nail traverses the canal.[14] In distal fractures, inadequate nail fit allows the distal fragment to translate and angulate, particularly if the distal interlocking screws are placed in a single plane.[15]

Plate Fixation (MIPPO): MIPPO relies on indirect reduction techniques. Malalignment typically results from improper plate contouring or failure to adequately restore the mechanical axis prior to securing the plate. Because the plate is applied eccentrically to the mechanical axis of the bone, failure to compress the plate flush against the bone can induce translational or angular deformities.[16] Unlike IMN, plating provides less inherent resistance to torsional forces unless specific lag screw or locked techniques are utilized properly.

External Fixation: External fixation is often utilized in high-energy open fractures. Malalignment in these frames typically arises from either initial docking errors during frame construction or secondary displacement due to pin loosening or frame bending. Sagittal plane deformities (sagging) can occur if the frame lacks adequate anteroposterior stiffness or if the patient bears weight prematurely before callus formation.[17]

Risk Factors: Multiple factors predispose a tibial fracture to malalignment. These are broadly categorized into anatomical/fracture-related factors, patient factors, and surgical/technical factors. [Table 2] summarizes the major risk factors and corresponding preventive strategies.

Table 2: Major Risk Factors and Preventive Strategies for Tibial Malalignment

Risk Factor Category	**Specific Risk Factor**	**Preventive Surgical Strategy**
Anatomical / Fracture	Metaphyseal location (Proximal/Distal)	Use of poller (blocking) screws to narrow the functional canal diameter.
Anatomical / Fracture	Intact fibula / Isolated tibia fracture	Careful monitoring for varus drift; consider prophylactic fibular osteotomy or plating.
Patient Factors	Poor bone stock (Osteoporosis)	Multiplanar interlocking screws; extended immobilization; adjunctive plating.
Surgical / Technical	Eccentric nail entry point	Strict fluoroscopic verification of true AP and lateral views before opening the cortex.
Risk Factor Category	Specific Risk Factor	Preventive Surgical Strategy
Surgical / Technical	Knee flexion during IP nailing	Use suprapatellar (SP) approach to allow semi-extended positioning, reducing extensor pull.

Recent studies emphasize the impact of these factors. A 2024 cohort study investigating distal tibial fractures treated with IMN demonstrated a malalignment rate of approximately 13%, identifying large nail diameter (>10mm) in a wide metaphysis as a risk factor, while multiplanar distal interlocking screws proved protective against deformity.[15]

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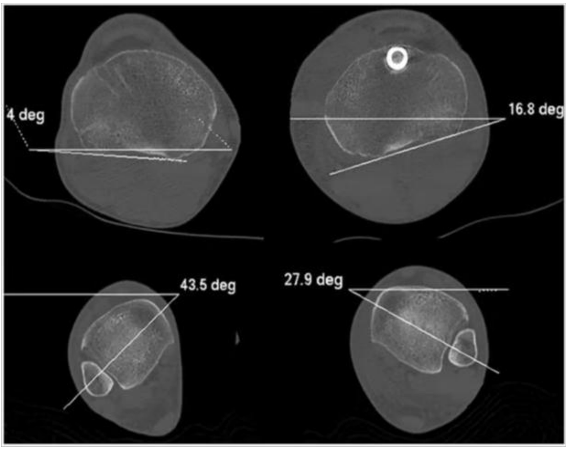

Figure 1: CT-based assessment of tibial rotational torsion. Proximal slices reference the dorsal aspect of the tibial plateau, while distal slices reference the tibiotalar joint. The difference between the injured and uninjured limbs defines the degree of rotational malalignment.

Source: Hendrickx et al., 2024 / Open Access

Assessment and Measurement

Accurate assessment of alignment is mandatory. Clinical examination, such as evaluating the thigh-foot angle, is highly subjective and historically unreliable for detecting subtle rotational differences.

Standard orthogonal radiographs are the primary modality for evaluating coronal and sagittal alignment. However, standard radiographs are highly sensitive to projectional artifacts; slight external rotation of the leg can obscure a varus deformity or project a false starting point.[18]

Computed tomography (CT) has emerged as the gold standard for assessing rotational malalignment [Figure 1]. Recent CT-based analyses demonstrate that rotational malalignment (>10°) occurs in approximately 30% of patients following tibial IMN.[13,19] Alarmingly, a substantial portion of these deformities go unrecognized on standard post-operative radiographs and clinical examinations.

Figure 2: Progression of malalignment in a distal tibial fracture. Immediate postoperative radiographs (center) show acceptable alignment, but progression to varus malunion occurs over time with failure of distal interlocking hardware (right).

Source: Chaudhry et al., 2024 / Open Access

Clinical Consequences

The biomechanical importance of restoring tibial alignment cannot be overstated. Deformity shifts the weight-bearing mechanical axis, which alters load distribution across the knee and ankle cartilage. In the coronal plane, a residual varus deformity shifts weight bearing to the medial compartment of the knee, significantly accelerating medial unicompartmental osteoarthritis.[5] The ankle joint is similarly intolerant of malalignment due to its highly constrained hinging articulation.

Beyond late-stage degenerative changes, malalignment is an independent predictor of failure of fracture healing. Tibial malalignment acts biomechanically to increase shear forces at the fracture site, which disrupts the delicate microvascular angiogenesis required for callus formation. Studies have shown a 3- to 6-fold increase in the risk of delayed union and nonunion in patients with coronal or sagittal malalignment >5°.[3,20] [Figure 2] illustrates the late collapse and hardware failure associated with poorly controlled distal varus.

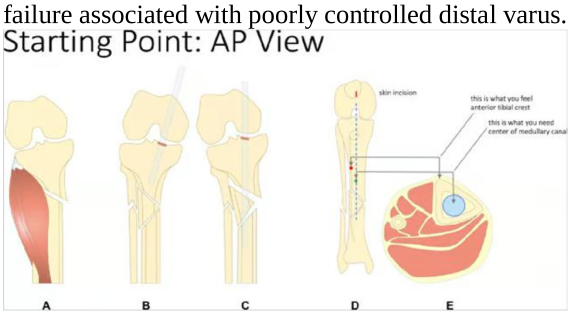

Figure 3: Anatomical deforming forces in proximal tibial fractures. The unbalanced pull of the lateral leg extensor muscles inherently draws the proximal fragment into valgus, emphasizing the need for precise starting points and blocking screws.

Source: J Orthop Trauma / Open Access Archive

Prevention and Practical Surgical Pearls

Minimizing malalignment requires meticulous surgical execution and the use of adjunctive techniques. [Figure 3] highlights the muscular forces that must be overcome surgically.

- Poller (Blocking) Screws: Placed adjacent to the intramedullary nail path, poller screws functionally narrow the metaphyseal canal and force the nail into the center of the medullary space. Systematic review-level evidence confirms that the use of poller screws significantly reduces the rates of coronal malunion and nonunion.[21]
- Suprapatellar (SP) Approach: The SP approach allows the limb to be positioned in semi-extension (15° to 20° of flexion) rather than hyperflexion. This dramatically relaxes the pull of the patellar tendon, mitigating the risk of procurvatum.[22] However, recent evidence indicates that while the SP approach improves sagittal reduction, it may not significantly reduce the rate of CT-defined rotational malalignment compared to the IP approach, with both showing rates around 30%.[13]
- Multiplanar Interlocking: For distal-third fractures, securing the nail with locking screws in multiple planes (e.g., anteroposterior and mediolateral) provides superior resistance to torsional and angular forces, reducing the risk of late varus collapse.[15]
- Fibular Fixation: In cases of distal tibia fractures with concomitant fibular fractures at the same level, stabilizing the fibula with a plate can restore lateral column length and serve as a template to prevent valgus/varus drift of the tibia.[23]

Limitations of the Current Evidence

While the literature on tibial malalignment is extensive, it remains largely composed of retrospective cohorts and narrative reviews, introducing inherent selection bias. There is also marked heterogeneity in how different studies define and measure malalignment—some rely strictly on clinical measurement, while others utilize highly sensitive CT scans. Furthermore, the correlation between mild rotational malalignment (10°-15°) and long-term functional impairment remains debated, as some patients tolerate mild asymmetry without functional deficit.[13]

CONCLUSION

Malalignment following tibial shaft fracture fixation remains a prevalent and biomechanically significant complication that negatively impacts union rates and long-term joint health. Fractures in the metaphyseal zones are particularly vulnerable. Successful management requires a deep understanding of plane-specific deforming forces. The integration of modern techniques, such as the suprapatellar approach, multiplanar distal interlocking, and the strategic use of poller screws, significantly enhances the surgeon's ability to restore and maintain anatomical alignment. Furthermore, surgeons should recognize the high incidence of rotational deformity and consider low-dose CT profiling when clinical suspicion arises.

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