Current Perspectives on Intramedullary Nailing and MIPO in Distal Tibial Fracture Management

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Abstract

Background:. Distal tibial fractures present a unique clinical challenge due to their subcutaneous location, limited soft tissue coverage, and complex biomechanical environment. The management of these injuries has evolved significantly, with a strong emphasis on achieving stable fixation while preserving the biological environment and minimizing soft tissue compromise. Two widely adopted fixation methods are intramedullary nailing (IMN) and minimally invasive plate osteosynthesis (MIPO). Both techniques are supported by substantial literature, yet controversies remain regarding their relative superiority in terms of alignment, union rates, complications, and functional outcomes. Intramedullary nailing offers the advantages of load-sharing biomechanics, smaller incisions, and early mobilization. However, its use in distal tibial fractures is technically demanding, with higher risks of malalignment and anterior knee pain. MIPO, on the other hand, provides direct control of fracture alignment through biological plating principles, minimizing periosteal stripping and preserving blood supply. While it reduces the incidence of malalignment, it is associated with increased surgical exposure, longer operative times, and potential risks of soft tissue irritation or infection. Comparative studies highlight that union rates are generally similar between IMN and MIPO, though IMN allows earlier weight bearing, whereas MIPO ensures better radiographic alignment. Functional outcomes vary, with some reports favoring IMN for patient mobility, while others support MIPO for reduced malalignment. Soft tissue complications remain more common with plating, particularly in cases with compromised skin. Meta-analyses suggest no significant difference in long-term functional outcomes, but patient-specific factors—such as bone quality, comorbidities, and fracture morphology—play a decisive role in method selection. The current perspective emphasizes individualized treatment planning rather than a universal preference for one technique. Emerging concepts include hybrid fixation methods, improved nailing techniques with distal locking options, and anatomically contoured plates for MIPO. Future directions focus on biomechanically optimized implants, computer-assisted reduction, and enhanced perioperative protocols to improve outcomes. In conclusion, both IMN and MIPO remain viable and effective treatment options for distal tibial fractures, with choice determined by fracture configuration, patient factors, and surgeon expertise. A balanced approach integrating biomechanical principles with biological fixation strategies offers the best potential for favorable outcomes in this challenging fracture pattern.

Keywords: *Intramedullary Nailing, MIPO, Distal Tibial Fracture Management*

Introduction

Distal tibial fractures represent approximately 10–15% of all tibial fractures and remain one of the most complex injuries to manage in orthopedic trauma surgery. Their subcutaneous anatomical location, limited muscular envelope, and tenuous blood supply make them particularly susceptible to complications such as delayed union, nonunion, malalignment, and soft tissue breakdown. In addition, the proximity of the fracture line to the ankle joint often complicates fixation choices, as both biomechanical and biological factors must be carefully balanced. Unlike diaphyseal tibial fractures, where intramedullary nailing has become the gold standard, the management of distal tibial fractures continues to provoke debate among trauma surgeons [1].

The two most widely used surgical techniques for distal tibial fracture fixation are **intramedullary nailing (IMN)** and **minimally invasive plate osteosynthesis (MIPO)**. IMN, with its load-sharing properties and minimally invasive nature, offers advantages of early mobilization and reduced soft tissue disruption. However, its application in the distal tibia is technically demanding, with higher risks of malreduction, anterior knee pain, and potential difficulties in distal locking due to the metaphyseal widening of the bone. On the other hand, MIPO emphasizes biological fixation principles, with plates applied submuscularly or subcutaneously through limited incisions. This technique preserves fracture hematoma and periosteal blood supply, improving the biological environment for fracture healing. Nonetheless, it carries its own risks, including hardware prominence, deep infection, and delayed mobilization due to less stable fixation in osteoporotic bone [2].

Despite numerous studies, randomized controlled trials, and systematic reviews comparing these two modalities, there is still no absolute consensus on which method provides superior outcomes. The literature suggests that union rates between IMN and MIPO are largely comparable, though IMN favors early weight bearing and MIPO tends to provide more accurate radiographic alignment. However, complication profiles differ, with malalignment more common in IMN and soft tissue irritation or infection more frequent in MIPO [3]. These variations highlight the importance of individualized treatment strategies, considering patient comorbidities, fracture morphology, and surgeon expertise.

The aim of this review is to critically analyze the current perspectives on intramedullary nailing versus minimally invasive plate osteosynthesis in the management of distal tibial fractures. By consolidating available evidence, evaluating biomechanical and clinical outcomes, and identifying gaps in the literature, this article seeks to provide an updated framework for decision-making. Furthermore, future directions in implant design, surgical technique, and perioperative care will be explored, emphasizing the need for a tailored, patient-centered approach in achieving optimal outcomes for these challenging injuries [4].

Anatomical Considerations of the Distal Tibia

The distal tibia is a unique anatomical region that poses significant challenges in fracture fixation due to its structural and biological characteristics. Unlike the diaphyseal segment, the distal tibia demonstrates a metaphyseal flare with a relatively wide medullary canal, making it difficult to achieve stable intramedullary fixation. The cortical bone in this region gradually transitions to cancellous bone, which compromises the purchase of screws and distal interlocking bolts, particularly in intramedullary nailing. This anatomical variation contributes to the risk of malalignment and implant failure if not properly addressed [5].

Another critical factor is the limited soft tissue envelope surrounding the distal tibia. The anteromedial surface is subcutaneous, with minimal muscle coverage, rendering the bone vulnerable to soft tissue compromise and infection following injury or surgical intervention. This is particularly important in high-energy fractures, where initial trauma may already compromise the skin and vascularity. Minimally invasive techniques such as MIPO are designed to preserve the periosteal blood supply and minimize surgical dissection, addressing some of these anatomical limitations. Nevertheless, the close proximity of neurovascular structures and the thin soft tissue layer increase the risk of wound complications, especially with plate fixation [6].

Biomechanically, the distal tibia is subjected to complex loading forces transmitted from the knee to the ankle joint. The metaphyseal region often sustains extra-articular or partial articular fractures that require careful alignment to avoid long-term functional impairment. Even slight malalignment, particularly in the coronal or sagittal plane, can significantly alter ankle biomechanics, leading to early degenerative arthritis and persistent functional disability. Therefore, precise anatomical reduction and stable fixation are paramount, regardless of whether intramedullary nailing or MIPO is employed [7].

The articular extension of distal tibial fractures further complicates management. Intra-articular involvement, as in pilon fractures, often necessitates direct visualization or adjunct fixation methods to restore the joint surface accurately. Although the current review focuses on extra-articular distal tibial fractures, the anatomical principles remain critical, as any compromise in alignment or stability has direct consequences on long-term outcomes. Consequently, a thorough understanding of the distal tibial anatomy, soft tissue envelope, and biomechanical environment is essential in selecting the appropriate fixation technique [8].

Biomechanics of Distal Tibial Fractures

The biomechanics of distal tibial fractures are complex due to the transitional nature of the distal tibia from the diaphyseal shaft to the articular surface of the ankle joint. The metaphyseal region is wider and composed predominantly of cancellous bone, which offers less resistance to implant fixation compared to the denser diaphyseal cortex. This anatomical variation results in reduced stability of intramedullary devices and plate screws, particularly when fractures occur close to the plafond. The load transmission in this region is multidirectional, with axial, torsional, and bending forces acting simultaneously, further complicating stable fixation [9].

Axial loading across the distal tibia is of particular concern because even minor malalignment can significantly alter force distribution across the ankle joint. Varus or valgus malalignment exceeding 5 degrees has been shown to increase uneven joint loading, predisposing patients to early post-traumatic osteoarthritis. Similarly, sagittal malalignment, whether procurvatum or recurvatum, can disturb ankle kinematics and gait mechanics. Therefore, fixation techniques in distal tibial fractures must not only ensure stability but also restore precise alignment to minimize long-term functional impairment [10].

Rotational stability presents another challenge in distal tibial fractures. Intramedullary nailing provides good resistance to bending and axial forces but can be less effective in controlling rotation, particularly in short distal fragments where the nail has limited cortical contact. Distal interlocking screws are critical for rotational stability, but their effectiveness depends on bone quality and screw placement. Conversely, plating techniques, especially with MIPO, allow for direct control of rotation through plate contouring and multiple fixation points across the fracture. However, this may be compromised if screw fixation in cancellous bone is inadequate [11].

Load-sharing versus load-bearing principles also distinguish IMN from MIPO biomechanically. IMN acts as a load-sharing device, allowing partial transfer of stresses through the bone-implant construct, which promotes secondary bone healing through callus formation. In contrast, MIPO constructs are generally load-bearing, with the plate assuming the majority of forces until bone consolidation occurs. While this may reduce micromotion and enhance alignment control, it can lead to stress shielding and delayed callus formation in certain cases. The selection between these modalities should therefore be guided by the desired balance between mechanical stability and biological healing potential [12].

Intramedullary Nailing (IMN): Principles and Techniques

Intramedullary nailing has long been established as the gold standard for diaphyseal tibial fractures, and its application has been extended into the management of distal tibial fractures. The principle behind IMN is biological fixation through a load-sharing device placed centrally within the medullary canal. By positioning the implant in line with the mechanical axis of the limb, intramedullary nails provide stability against axial loads while permitting controlled micromotion, which encourages secondary bone healing through callus formation. The minimally invasive nature of nail insertion also preserves periosteal blood supply and fracture hematoma, both of which are essential for fracture healing [13].

The technique of IMN in distal tibial fractures, however, requires significant surgical expertise. Due to the metaphyseal flare and the widening of the medullary canal, achieving stable fixation in the distal fragment can be challenging. Modern nails are designed with multiple distal locking options, including multiplanar and angular stable interlocking screws, which enhance fixation in short segments of cancellous bone. Accurate entry point selection is crucial, typically just medial to the lateral tibial spine and in line with the medullary canal, to prevent malalignment. In distal fractures, careful fluoroscopic guidance during reduction and locking is mandatory to ensure proper alignment and implant positioning [14].

The technique also requires adjunctive measures to optimize outcomes. Blocking screws, also known as Poller screws, are often employed in metaphyseal fractures to guide the nail and prevent malalignment by narrowing the effective medullary canal. These screws act as "internal guides" and help in maintaining reduction, especially in cases with short distal fragments. Additionally, careful intraoperative assessment of alignment in both coronal and sagittal planes is essential, as malreduction is a well-documented complication of IMN in the distal tibia. Advanced intraoperative imaging and reduction tools, such as external fixators or distractors, may be used to assist in achieving and maintaining alignment during nail insertion [15].

Postoperatively, IMN typically allows earlier weight bearing compared to plate fixation, due to its intramedullary location and load-sharing biomechanics. This is particularly beneficial for patients requiring rapid mobilization, such as the elderly or polytraumatized individuals. However, the technique is not without drawbacks, as knee pain from the entry point and risks of malalignment continue to pose significant challenges. Nevertheless, when performed with meticulous attention to surgical principles and aided by modern nail designs, IMN remains a reliable option for distal tibial fractures [16].

Advantages of Intramedullary Nailing in Distal Tibia

One of the primary advantages of intramedullary nailing (IMN) in the treatment of distal tibial fractures is its minimally invasive nature. Since the nail is introduced through a small incision at the proximal tibia and advanced within the medullary canal, the fracture site itself is not directly exposed. This preserves the periosteal blood supply and fracture hematoma, both of which are critical for secondary bone healing. Compared to open plating methods, IMN reduces soft tissue disruption, lowering the risk of infection and promoting a more favorable biological environment for healing [17].

Another major benefit is the **biomechanical efficiency** of intramedullary nails. As a load-sharing device, the nail aligns closely with the mechanical axis of the limb, allowing axial forces to be transmitted through both the bone and the implant. This facilitates controlled micromotion at the fracture site, which stimulates callus formation and secondary bone healing. The central location of the nail also provides high resistance against bending forces, making IMN particularly advantageous in weight-bearing bones such as the tibia. These mechanical properties often permit earlier weight bearing compared to plating techniques, which can significantly enhance functional recovery [18].

IMN also offers distinct advantages in cases of polytrauma or in patients requiring early mobilization. Early weight bearing not only reduces the risk of complications such as deep vein thrombosis, pulmonary embolism, and muscle atrophy, but also improves patient independence and rehabilitation outcomes. For elderly patients, who are often more vulnerable to complications from prolonged immobility, IMN is particularly beneficial. The intramedullary location of the implant further minimizes stress concentration on the skin and soft tissue envelope, an important factor in distal tibial fractures where the anteromedial cortex is subcutaneous and prone to breakdown [19].

In addition, advances in implant design have expanded the indications and advantages of IMN in the distal tibia. Modern nails now incorporate multiplanar distal locking options, angular stability, and compatibility with blocking screw techniques, all of which improve fixation in short distal fragments. These improvements have reduced the incidence of malalignment and implant failure historically associated with distal tibial nailing. Furthermore, the percutaneous approach associated with IMN makes it a favorable option in patients with compromised soft tissues, where large incisions for plating may increase the risk of wound complications [20].

Limitations and Complications of Intramedullary Nailing

Despite its popularity, intramedullary nailing (IMN) for distal tibial fractures carries several limitations and potential complications. A major concern is the risk of malalignment, particularly in fractures close to the tibial plafond where the metaphyseal flare provides limited cortical contact for the nail. Malreduction in the coronal or sagittal plane, resulting in varus, valgus, procurvatum, or recurvatum deformities, remains one of the most frequently reported complications. These malalignments may not be immediately apparent intraoperatively but can manifest postoperatively as functional deficits and early degenerative changes in the ankle joint [21].

Another common complication associated with IMN is **anterior knee pain**, which is reported in up to 40% of patients. This discomfort is often related to the entry point of the nail, damage to the patellar tendon, or irritation from proximal locking screws. While knee pain is not directly linked to fracture healing, it can significantly affect patient satisfaction and long-term functional outcomes. Modifications in surgical technique, such as using a parapatellar or suprapatellar entry point, have been developed to mitigate this issue, though evidence regarding their superiority remains mixed [22].

Nonunion and delayed union are additional concerns, particularly when fixation stability is suboptimal. Although IMN generally supports secondary bone healing, inadequate distal fixation in short fragments or poor reduction can impair healing progression. The risk of nonunion is also influenced by patient-related factors such as smoking, diabetes, or severe comminution. In some cases, hardware failure, including breakage of interlocking screws, may occur due to insufficient stability or premature weight bearing, necessitating revision surgery [23].

Infection, while less common with IMN compared to plating, is not absent. Deep infection is relatively rare due to the limited surgical exposure, but superficial infection at the entry site or around locking screw incisions may occur. Additionally, neurovascular injury, though uncommon, remains a potential risk during distal locking screw placement due to the proximity of major vessels and nerves. Finally, in osteoporotic bone, achieving adequate purchase with distal screws can be difficult, increasing the risk of fixation failure. These limitations highlight that although IMN offers many advantages, careful patient selection, meticulous technique, and appropriate implant choice are essential to minimize complications [24].

Minimally Invasive Plate Osteosynthesis (MIPO): Principles and Techniques

Minimally invasive plate osteosynthesis (MIPO) is based on the principle of biological fixation, aiming to provide stable mechanical support while preserving the vascularity of bone and surrounding soft tissues. Instead of exposing the fracture site through large incisions, MIPO employs small, strategically placed incisions that allow insertion of a pre-contoured plate in a submuscular or subcutaneous tunnel. This technique avoids extensive periosteal stripping, thus maintaining the fracture hematoma, which plays a vital role in secondary bone healing. By combining mechanical stability with biological preservation, MIPO has become a widely accepted technique for managing fractures of the distal tibia [25].

The surgical technique of MIPO involves indirect fracture reduction under fluoroscopic guidance, often aided by percutaneous clamps, external distractors, or reduction forceps. Once satisfactory alignment is achieved, a pre-contoured locking compression plate (LCP) is slid through the subcutaneous tunnel along the anteromedial aspect of the tibia. The plate is then fixed with locking or cortical screws inserted percutaneously through stab incisions. Locking plates, in particular, provide angular stability and are advantageous in osteoporotic or comminuted fractures where screw purchase may be compromised. By preserving the periosteal blood supply and fracture biology, MIPO promotes callus formation and enhances union rates [26].

Reduction accuracy is a critical step in MIPO since direct visualization of the fracture site is avoided. Reliance on intraoperative fluoroscopy is essential, and careful assessment of both coronal and sagittal alignment is necessary. Malreduction, although less common than with intramedullary nailing, can still occur if reduction tools are not adequately applied. To improve accuracy, temporary fixation devices such as K-wires, external fixators, or reduction frames are often employed before definitive plate fixation. The technique requires significant surgical expertise and familiarity with indirect reduction principles to achieve optimal outcomes [27].

Postoperative protocols following MIPO generally involve restricted weight bearing for several weeks, depending on fracture stability and patient factors. Unlike IMN, where early mobilization is often encouraged, MIPO constructs are primarily load-bearing and may require delayed weight bearing to avoid implant failure. However, the low rate of malalignment and the ability to achieve precise anatomical reduction are major strengths of this method. With advancements in implant design, including anatomically contoured distal tibial plates and locking options, the effectiveness and reproducibility of MIPO have significantly improved in recent years [28].

Advantages of MIPO in Distal Tibial Fractures

The primary advantage of minimally invasive plate osteosynthesis (MIPO) in distal tibial fractures is the preservation of biological integrity at the fracture site. By avoiding direct exposure of the fracture and limiting periosteal stripping, MIPO maintains the fracture hematoma and periosteal blood supply, which are critical for bone healing. This biological preservation significantly reduces the risk of delayed union and nonunion compared to traditional open plating techniques. The minimally invasive approach also minimizes soft tissue trauma, which is especially important in the distal tibia where the thin subcutaneous coverage predisposes the region to wound complications [29].

Another benefit of MIPO lies in its ability to achieve and maintain accurate anatomical alignment. The use of pre-contoured locking plates provides angular stability and allows precise control over both coronal and sagittal plane alignment. Unlike intramedullary nailing, which may be prone to malalignment in short distal fragments, MIPO provides multiple points of fixation along the metaphyseal bone, improving reduction accuracy. This alignment control translates into better restoration of the mechanical axis of the limb, thereby reducing the risk of post-traumatic arthritis and functional impairment in the ankle joint [30].

MIPO is particularly advantageous in managing comminuted fractures and fractures with intra-articular extension. The technique allows stable fixation even when direct manipulation of fragments is not possible, as the plate acts as an external splint bridging the comminuted zone. This bridging construct, combined with the locking mechanism, provides sufficient stability for bone healing while avoiding unnecessary disruption of the fracture environment. In cases with articular involvement, MIPO can be combined with limited open reduction of the joint surface followed by minimally invasive plate application, thereby integrating stability with joint congruity [31].

From a patient outcome perspective, MIPO has been associated with lower rates of malunion and higher rates of radiographic union compared to intramedullary nailing. While weight-bearing may be delayed compared to IMN, the reduced risk of malalignment and mechanical axis deviation is a strong clinical advantage. Additionally, MIPO avoids complications associated with intramedullary nail insertion, such as anterior knee pain, which can significantly affect long-term patient satisfaction. In cosmetically sensitive patients, the smaller incisions used in MIPO are also considered an advantage due to improved postoperative scarring [32].

Limitations and Complications of MIPO

While minimally invasive plate osteosynthesis (MIPO) offers clear biological and mechanical benefits, it is not without limitations and potential complications. One of the primary drawbacks is that plate constructs in the distal tibia are **load-bearing** rather than load-sharing. This means that the implant bears the majority of stress until fracture healing occurs, which can lead to stress shielding and delayed callus formation. Consequently, patients treated with MIPO often require a longer period of restricted weight bearing compared to those treated with intramedullary nailing. This limitation can delay rehabilitation and functional recovery, particularly in elderly or polytraumatized patients [33].

Another important complication associated with MIPO is related to the **soft tissue envelope of the distal**

tibia. Although the technique is minimally invasive, the subcutaneous location of the distal tibia means that hardware prominence and irritation of the skin are common postoperative complaints. Prominent plates may lead to persistent discomfort, necessitating secondary implant removal. Additionally, the limited soft tissue coverage predisposes patients to superficial wound infections and, in some cases, deep infections. These risks are heightened in patients with comorbidities such as diabetes, peripheral vascular disease, or in high-energy fractures with compromised skin [34].
Surgical technique-related complications must also be considered. Since MIPO relies on indirect reduction under fluoroscopic guidance, there is a risk of malreduction, particularly in rotational alignment. Excessive reliance on fluoroscopy can also increase operative time and radiation exposure for both the patient and surgical team. Furthermore, insertion of the plate through subcutaneous tunnels can occasionally cause injury to surrounding neurovascular structures if not performed meticulously. Plate contouring is another challenge; although pre-contoured implants are now available, achieving perfect anatomical adaptation may still be difficult, especially in cases with unusual anatomy [35].
Finally, implant failure is a recognized complication of MIPO, particularly in osteoporotic bone where screw purchase is poor. Screw loosening, plate breakage, or secondary displacement of the fracture can occur if adequate fixation is not achieved. Locking plates provide improved angular stability, but they are more expensive and not always available in resource-limited settings. Cost remains an additional limitation of MIPO compared to intramedullary nailing, which can be an important consideration in healthcare systems with constrained resources. Thus, while MIPO provides excellent biological preservation and alignment control, its limitations must be weighed carefully against patient-specific factors and fracture characteristics [36].

Comparative Studies: Union Rates and Healing Times

Union rates in distal tibial fractures managed with intramedullary nailing (IMN) and minimally invasive plate osteosynthesis (MIPO) have been extensively studied, with most reports indicating broadly similar overall healing outcomes. Both techniques preserve fracture biology, albeit through different mechanisms: IMN allows micromotion and secondary healing with callus formation, whereas MIPO preserves periosteal circulation and fracture hematoma to promote healing. Several randomized controlled trials (RCTs) and meta-analyses suggest that there is no statistically significant difference in union rates between the two techniques, with most studies reporting successful union in more than 90% of cases [37].
Despite similar union rates, differences emerge when analyzing **time to union**. IMN has often been associated with faster radiographic healing and earlier clinical consolidation compared to MIPO. This is largely attributed to its load-sharing properties, which stimulate callus formation through controlled micromotion at the fracture site. In contrast, MIPO constructs are load-bearing, which may reduce mechanical stimulation and lead to slightly prolonged healing times in some series. However, this difference is not universally reported, and some studies have demonstrated equivalent or even faster healing with MIPO, particularly in cases where anatomical reduction is achieved and preserved [38].
The risk of **delayed union and nonunion** also varies slightly between the two techniques. IMN carries a higher risk of delayed union in metaphyseal fractures due to instability at the distal fragment, especially when distal fixation is inadequate. Malalignment, commonly associated with IMN, can also negatively impact fracture healing. MIPO, on the other hand, generally demonstrates lower rates of delayed union, but complications such as infection or implant-related soft tissue irritation can indirectly impair healing. Notably, the introduction of modern distal locking options and the use of adjunctive blocking screws in IMN have significantly reduced the incidence of delayed union [39].
When considering **functional recovery and return to weight bearing**, IMN consistently demonstrates an advantage. Patients treated with IMN are typically mobilized earlier and allowed earlier partial or even full weight bearing, whereas MIPO often requires a period of restricted weight bearing until sufficient callus formation is visible radiographically. While this does not necessarily affect ultimate

union rates, it has a significant impact on rehabilitation and patient quality of life. Ultimately, while both IMN and MIPO achieve comparable union rates, IMN may offer earlier functional recovery, whereas MIPO may reduce the risk of malalignment and provide more accurate anatomical reduction [40].

Malalignment and Functional Outcomes: IMN vs MIPO

Malalignment is one of the most debated aspects when comparing intramedullary nailing (IMN) and minimally invasive plate osteosynthesis (MIPO) in distal tibial fractures. Due to the metaphyseal flare and widened canal of the distal tibia, IMN has historically been associated with higher rates of malreduction. Coronal plane deformities such as varus and valgus, as well as sagittal plane deformities including procurvatum and recurvatum, are frequently reported. Rotational malalignment, although less common, can also occur if distal fixation is inadequate. Malalignment rates of up to 20% have been described with IMN in distal tibial fractures, particularly before the advent of multiplanar distal locking screws and blocking screw techniques [41].

MIPO, on the other hand, offers superior control over alignment due to the use of pre-contoured locking plates and direct fixation of the metaphyseal fragment. This allows for accurate restoration of the mechanical axis, which is particularly important in preventing secondary ankle arthritis and functional deficits. Several comparative studies have consistently shown lower malalignment rates with MIPO compared to IMN. However, this advantage comes at the expense of delayed weight bearing, as MIPO constructs typically function as load-bearing devices requiring prolonged protection until sufficient healing is achieved [42].

Functional outcomes, as measured by scores such as the American Orthopaedic Foot and Ankle Society (AOFAS) score, Olerud-Molander Ankle Score (OMAS), and Short Form-36 (SF-36), are often influenced by these differences in alignment and rehabilitation. Patients treated with IMN generally experience earlier mobilization and faster return to daily activities due to earlier weight-bearing protocols. However, functional deficits related to malalignment may manifest later, potentially offsetting these early advantages. Conversely, patients treated with MIPO may experience slower initial recovery but demonstrate better long-term outcomes if alignment is well preserved [43].

It is important to note that patient-specific factors heavily influence functional outcomes. For example, younger patients with good bone stock may tolerate IMN well and achieve excellent outcomes despite minor malalignment. In contrast, elderly patients or those with osteoporotic bone may benefit more from MIPO due to its ability to provide stable fixation with locking plates. Surgeon experience and technical expertise are equally important, as both IMN and MIPO can yield excellent functional outcomes when executed properly. The choice of fixation method should therefore be individualized, balancing the risks of malalignment with the patient's rehabilitation needs and functional demands [44].

Soft Tissue and Infection Considerations

The distal tibia has a particularly vulnerable soft tissue envelope due to its subcutaneous location along the anteromedial aspect. This limited coverage makes the region highly susceptible to wound complications, especially following trauma or surgical intervention. Minimally invasive plate osteosynthesis (MIPO), while designed to preserve soft tissue integrity, still involves the placement of a plate directly beneath the skin, which can result in hardware prominence and irritation. These complications are especially common in thin patients with little subcutaneous tissue, leading to persistent discomfort and frequent requests for implant removal [45].

Infection remains a major concern in distal tibial fracture management, with plating techniques generally associated with higher infection rates compared to intramedullary nailing (IMN). The larger surface area of implants, coupled with their subcutaneous positioning in MIPO, creates a greater risk for bacterial colonization. Superficial infections may present as wound erythema or drainage, while deep infections can compromise fracture healing and necessitate implant removal. Meta-analyses comparing IMN and MIPO have consistently demonstrated lower infection rates with IMN, particularly in high-energy fractures with significant soft tissue compromise [46].

Intramedullary nailing, on the other hand, requires smaller incisions away from the zone of injury, which reduces the risk of wound breakdown. However, distal interlocking screw incisions can still pose a risk of localized infection, particularly if placed near areas of compromised skin. Despite this, the incidence of deep infection following IMN is generally lower than with plating. Importantly, IMN also avoids hardware irritation issues associated with MIPO, as the implant is centrally located within the bone rather than directly beneath the skin [47].

The choice between IMN and MIPO should therefore account for the condition of the soft tissues at the time of injury. In fractures with extensive soft tissue damage, such as open fractures or those with severe swelling, IMN may be preferable due to its less invasive approach in the distal segment. Conversely, in cases where skin condition is acceptable and precise alignment is critical, MIPO remains a viable option but requires meticulous wound care and close postoperative monitoring to prevent infection-related complications [48].

Biomechanical Comparisons of IMN and MIPO

Biomechanical studies comparing intramedullary nailing (IMN) and minimally invasive plate osteosynthesis (MIPO) in distal tibial fractures have provided important insights into their strengths and limitations. IMN functions as a **load-sharing device**, transmitting stress across both the implant and the bone. This property encourages secondary healing through callus formation and allows earlier weight bearing. In contrast, MIPO functions primarily as a **load-bearing construct**, where the plate assumes most of the mechanical load until fracture consolidation occurs. While this offers superior alignment control, it reduces micromotion at the fracture site, which may delay callus formation in some cases [49].

Resistance to **axial and bending forces** has been shown to be higher with IMN due to its intramedullary position, which aligns with the mechanical axis of the tibia. Nails are particularly effective in resisting sagittal and coronal bending stresses, making them favorable for early mobilization. However, IMN is less effective in resisting rotational forces in distal metaphyseal fractures, especially when the distal fragment is short. Distal locking screws provide rotational stability, but screw loosening or poor bone stock can compromise fixation. MIPO, with its multiple fixation points and angular stable screws, offers superior resistance to torsional stresses and rotational displacement [50].

Several biomechanical investigations have demonstrated that MIPO constructs provide more accurate reduction and better stability in controlling angular deformities compared to IMN. Plates, especially locking plates, act as internal fixators and maintain alignment through fixed-angle screw-plate interfaces. This reduces the risk of malalignment but comes at the cost of delayed functional loading, as excessive early weight bearing can jeopardize plate stability and lead to implant failure. Thus, while MIPO ensures stability in terms of alignment, it demands careful postoperative weight-bearing protocols [51].

Recent advancements have attempted to combine biomechanical strengths of both techniques. For IMN, innovations such as multiplanar distal locking, angular stable screws, and the use of Poller (blocking) screws have significantly improved rotational and angular stability in distal tibial fractures. Similarly, advancements in plate technology, such as anatomically contoured distal tibial plates and locking compression plates, have enhanced fixation strength while preserving biology. Despite these improvements, biomechanical studies consistently highlight that IMN remains superior for axial loading and early functional rehabilitation, while MIPO offers better control of alignment and torsional stability [52].

Conclusion

Distal tibial fractures remain one of the most technically demanding injuries in orthopedic trauma, requiring careful consideration of both biomechanical and biological principles. Intramedullary nailing (IMN) and minimally invasive plate osteosynthesis (MIPO) have emerged as the two most widely practiced fixation methods, each with distinct advantages and limitations. IMN offers the benefits of a minimally invasive, load-sharing construct that facilitates early mobilization and faster rehabilitation, though it carries a higher risk of malalignment and complications such as anterior knee pain. MIPO, in contrast, provides superior control of alignment and maintains the biological environment of fracture healing, but is associated with delayed weight bearing, hardware prominence, and higher infection risks. The evidence indicates that union rates between IMN and MIPO are largely comparable, though functional recovery timelines and complication profiles differ. While IMN allows earlier weight bearing and often faster return to activities, MIPO tends to produce more accurate anatomical reduction and reduced malalignment rates. Ultimately, no single method can be universally recommended, as fracture configuration, soft tissue status, patient comorbidities, and surgeon expertise all play critical roles in determining the optimal strategy.

Future directions in distal tibial fracture management include continued refinement of implant technology, with intramedullary nails incorporating multiplanar distal locking and angular stability, and plates designed with improved anatomical contouring to enhance fixation strength while preserving biology. Hybrid approaches that combine the strengths of both techniques, along with emerging technologies such as computer-assisted reduction and patient-specific implants, may further improve outcomes.

In conclusion, both IMN and MIPO remain effective and reliable options for distal tibial fracture fixation. The decision should be individualized, guided by patient-specific factors and the surgeon's technical expertise. By balancing biological preservation with mechanical stability, and leveraging advancements in surgical techniques and implant design, surgeons can optimize outcomes for this challenging fracture pattern.

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