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Methods of Ankle Arthrodesis: Review Article

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Abstract:

Ankle arthrodesis remains the gold standard surgical procedure for managing end-stage ankle arthritis, particularly in patients with severe deformity, post-traumatic degeneration, or failed conservative treatment. Multiple techniques for ankle fusion have been developed, broadly categorized into internal and external fixation methods, each with distinct biomechanical principles, indications, and clinical outcomes. Internal fixation, utilizing screws, plates, or intramedullary devices, is widely preferred due to its ability to provide rigid stability, high union rates, and improved patient comfort. In contrast, external fixation plays a critical role in complex cases involving poor soft-tissue conditions, infection, bone defects, or neuropathic joints, offering advantages such as deformity correction and minimal internal hardware. Understanding the advantages, limitations, and appropriate indications of each technique is essential for optimizing surgical outcomes and minimizing complications.

Keywords: Ankle arthrodesis, Internal fixation, External fixation, End-stage ankle arthritis, Ilizarov fixator, Tibiotalar fusion, Biomechanics, Deformity correction

Introduction:

Osteoarthritis of the ankle affects an estimated 1% of the global adult population. The predominant etiology is post-traumatic, accounting for over 70% of cases. Common antecedent injuries include malleolar fractures, ligamentous lesions, and fractures of the tibial plafond. Secondary arthritis arises from systemic or neurogenic conditions, such as rheumatoid arthritis, hemochromatosis, hemophilia, and neuropathic arthropathy.(1)

Primary osteoarthritis is comparatively rare, observed in approximately 10% of cases. A varus malalignment is present in the majority of patients, regardless of the underlying cause. End-stage ankle arthritis culminates in significant physical and psychological disability; its associated burden is at least equivalent to that of end-stage hip arthritis.(1)

The surgical approach and technique for ankle arthrodesis exhibit considerable variability, with more than thirty distinct methods for tibiotalar arthrodesis documented in the literature. Selection of the optimal approach must be predicated on a comparative analysis of the advantages and limitations inherent to each fixation strategy, while also incorporating patient-specific factors and the underlying etiology. Both internal and external fixation methodologies are well-established. Primary advantages of internal fixation include relative technical ease of application, a favorable profile for mitigating risks of nonunion and surgical site infection, and its capacity to neutralize detrimental biomechanical forces.(2)

External fixation retains a distinct role in specific clinical contexts. This technique is indicated in compromised peri-ankle soft tissue envelope, insufficient bone stock for stable internal implant fixation or when a segmental bone defect necessitates concomitant tibial lengthening via distraction osteogenesis. In the absence

of these conditions, prevailing clinical guidelines favor internal compression methods, typically achieved with screw or plate constructs.(3)

Internal fixation in ankle arthrodesis:

Internal ankle arthrodesis represents a standard surgical intervention for managing end-stage ankle arthritis. Since the late 1970s, internal fixation has supplanted external fixation as the predominant method for primary ankle fusion. This transition is attributable to advancements in implant design, superior biomechanical stability, and increased postoperative patient comfort. The primary objective of internal fixation is to provide rigid stabilization and generate compressive forces across the tibiotalar joint, thereby facilitating primary bone healing and ensuring consistent, high rates of arthrodesis.(4)

Internal ankle arthrodesis constitutes the definitive surgical intervention for younger, high-demand patients and for individuals presenting with significant deformity, avascular necrosis, or poor soft-tissue tolerance for total ankle arthroplasty. The predominant operative strategy for achieving arthrodesis is internal fixation. This method has been demonstrated to yield favorable outcomes, providing rigid fixation and a high rate of osseous union with minimal complication rates.(5)

The primary merits of internal fixation include the extensive availability of the requisite hardware, its comparatively low cost, the technical simplicity of its application, and its well-established clinical efficacy in appropriate indications. The procedure itself can be executed utilizing either arthroscopic or conventional open surgical techniques.

The spectrum of open surgical approaches encompasses anterior, lateral transfibular, and mini-open methodologies.(5)

Biomechanical Basis of Internal Ankle Arthrodesis

The ankle joint is a highly congruent articulation that transmits substantial forces during gait, reaching up to five to seven times body weight. Consequently, a successful internal arthrodesis requires a fixation construct with sufficient mechanical strength to resist three primary loading modes: axial compression, torsional forces, and bending stresses in the sagittal and coronal planes.

Biomechanical evidence indicates that rigid internal fixation combined with compression effectively minimizes interfragmentary micromotion at the arthrodesis site, thereby promoting osseous union. Furthermore, constructs integrating compression screws with neutralization plates demonstrate superior overall stiffness in comparison to configurations employing screws alone, a mechanical advantage that is most pronounced under torsional and bending loads.(6)

Indications for Internal Ankle Arthrodesis

Internal fixation represents the most appropriate surgical strategy for ankle arthrodesis in patients meeting specific clinical and anatomical criteria. The principal indications include: (A) end-stage primary or post-traumatic osteoarthritis, (B) rheumatoid arthritis in the absence of active infection, and (C) failure of comprehensive conservative management. This approach is also applicable in (D) select cases of failed total ankle arthroplasty and (E) in the presence of adequate bone stock and a viable soft-tissue envelope. Internal arthrodesis, employing screw, plate, or retrograde intramedullary nail fixation, is generally the preferred technique when active infection is absent and bone quality is sufficient to achieve stable construct fixation.(7)

Contraindications

Contraindications to internal ankle arthrodesis primarily comprise active local infection or osteomyelitis, severe Charcot neuroarthropathy, poor bone stock, a compromised soft-tissue envelope, and severe peripheral vascular disease. In these clinical scenarios, external fixation is generally the preferred alternative stabilization method.(6)

Surgical Approaches for Internal Ankle Arthrodesis

Multiple surgical approaches are utilized to perform internal ankle arthrodesis, each characterized by distinct technical attributes and specific clinical indications. The anterior approach affords excellent visualization of the tibiotalar joint, thereby facilitating precise osseous alignment; however, it is associated with an elevated risk of wound complications. The transfibular, or lateral, approach provides extensive joint exposure and enables the use of the resected fibula as a local autograft.

It is frequently employed in the setting of post-traumatic arthritis. The posterior approach is particularly advantageous when anterior soft-tissue integrity is compromised and allows for concomitant Achilles tendon lengthening if required. The arthroscopic technique represents a minimally invasive option, indicated for patients with minimal coronal plane deformity, typically less than 10°. This method is correlated with diminished intraoperative blood loss and a reduced incidence of wound-related complications.(8)

Joint Preparation

The methodical preparation of the articular surfaces is the most critical procedural step in internal ankle arthrodesis. This process encompasses four principal technical objectives: the complete excision of all residual articular cartilage, the precise resection of sclerotic subchondral bone to expose viable, bleeding cancellous bone surfaces, the conscientious preservation of maximal bone stock, and the creation of multiple subchondral perforations to augment the local biology for fusion. Inadequate execution of this preparatory phase, resulting in poorly prepared joint surfaces, constitutes a predominant etiological factor in the development of postoperative nonunion.(9)

Internal Fixation Techniques

1. Crossed Screw Fixation

Crossed screw fixation represents a common internal fixation technique for ankle arthrodesis. This method typically employs two or three large-diameter cancellous screws (Figure 1). The screws are positioned from the tibia into the talus, generating direct compression across the arthrodesis site. The principal advantages of this technique are its technical simplicity and minimal implant bulk. However, its disadvantages include relatively lower torsional stability compared to other constructs and an elevated risk of fixation failure in osteoporotic bone.(10)

Figure (1): Radiographs at 5 years show solid fusion of the ankle in physiological alignment and no signs of adjacent joint arthritis. (11)

2. Plate Fixation

Plate fixation for ankle arthrodesis can be achieved through anterior or lateral application. This method provides enhanced resistance to bending forces compared to other fixation techniques and is particularly useful in

cases involving significant deformity or bone loss. Biomechanical analyses indicate that a plate construct alone confers stability comparable to a three-screw construct, though it is biomechanically inferior to constructs combining plate and screw fixation.(1)

3. Combined Plate and Screw Fixation

The combined plate and screw fixation construct demonstrates superior biomechanical stability compared to other fixation methods. This technique provides the highest overall mechanical rigidity. In this configuration, the interfragmentary compression screws confer primary axial stability, while the neutralization plate functions to resist torsional and bending moments. Consequently, it exhibits significantly greater stiffness across all anatomical planes. This enhanced biomechanical profile is correlated with elevated clinical rates of successful arthrodesis.(12)

4. Intramedullary Fixation

Intramedullary fixation represents a standard technique for tibiotalocalcaneal arthrodesis (Figure 2). Its primary indications include revision arthrodesis and the management of severe hindfoot deformity. The construct functions biomechanically as a load-sharing device.(13)

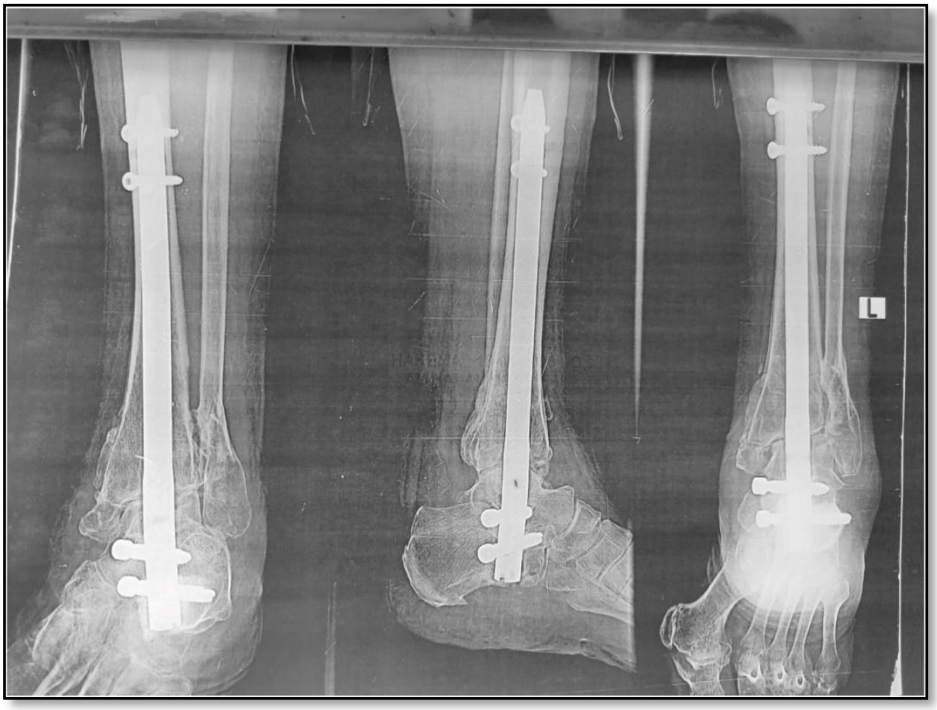

Figure 2: Illustration of a tibio-talo-calcaneal intramedullary nail construct for tibio-talo-calcaneal arthrodesis. (14)

Alignment in Internal Arthrodesis

Optimal alignment is a critical determinant of a successful ankle arthrodesis. The recommended fusion position comprises neutral dorsiflexion, 0 to 5 degrees of hindfoot valgus, and slight external rotation relative to the contralateral limb. Deviation from this alignment, or malunion, precipitates aberrant biomechanical loading and altered gait mechanics. Consequently, it accelerates the progressive degeneration of the ipsilateral subtalar and Chopart joints.(3)

Outcomes of Internal Ankle Arthrodesis

Internal ankle arthrodesis is associated with a reported osseous union rate of 85–95%. The procedure provides substantial pain relief for the majority of patients and results in high levels of patient satisfaction. When compared to open surgical techniques, arthroscopic internal arthrodesis achieves comparable union rates and is

associated with a reduced incidence of postoperative wound complications in appropriately selected patient cohorts.(7)

Complications

Internal ankle arthrodesis is associated with several potential postoperative complications. The most frequently encountered complications include surgical wound compromise, nonunion or delayed union of the arthrodesis site, and hardware failure or irritation. Additional risks consist of deep or superficial infection, malunion resulting in suboptimal alignment, and the subsequent development of adjacent joint arthritis. Identified patient and technical risk factors that may predispose individuals to these adverse outcomes comprise active tobacco use, diabetes mellitus, compromised bone quality, and inadequate surgical fixation.(7)

External Fixation in Ankle Arthrodesis:

While internal fixation is commonly used, external fixation remains essential in complex, high-risk cases, providing stable fixation with minimal soft-tissue disruption, allowing gradual deformity correction, sustained compression, and adaptability in challenging anatomical or biological conditions.(15)

Biomechanical Principles of External Fixation

Successful ankle arthrodesis requires several key technical objectives: adequate articular surface preparation, the application of stable fixation, the provision of compression across the fusion site, and the maintenance of proper limb alignment. External fixation constructs offer multiplanar stability and permit the application of controlled axial compression. This compression enhances the arthrodesis process by optimizing bone-to-bone contact and minimizing deleterious micromotion at the fusion interface.(16)

Specifically, circular external fixation systems achieve even load distribution through tensioned wires and rings, a mechanism that reduces localized stress shielding and can facilitate periosteal callus formation. In contrast to rigid internal fixation, external fixation allows for controlled dynamic loading, a mechanical environment demonstrated to stimulate osteogenesis. From a biomechanical perspective, the external fixation construct is particularly effective in resisting torsional and shear forces. These forces are critically important at the tibiotalar joint, especially when fusion is performed in the context of compromised bone quality, such as in neuropathic or osteoporotic bone.(17)

Types of External Fixation Used in Ankle Arthrodesis

1-Uniplanar External Fixation

Uniplanar external fixation is the simplest form used in ankle arthrodesis, consisting of tibial and calcaneal pins connected by a single external bar, offering technical simplicity, shorter operative time, and minimal hardware. However, due to limited rotational and multiplanar stability, inferior biomechanical strength, and poor deformity correction, it is rarely used as a definitive fixation method in modern practice.(10)

2-Biplanar External Fixation

Biplanar external fixation employs two orthogonal planes to enhance stability and improve osseous alignment through tibial, talar, and calcaneal pin placement. Although it offers greater stability than uniplanar systems and is relatively simple to apply, its limited multiplanar stability and restricted capacity for gradual deformity correction have led to its replacement by circular external fixation in complex ankle arthrodesis.(18)

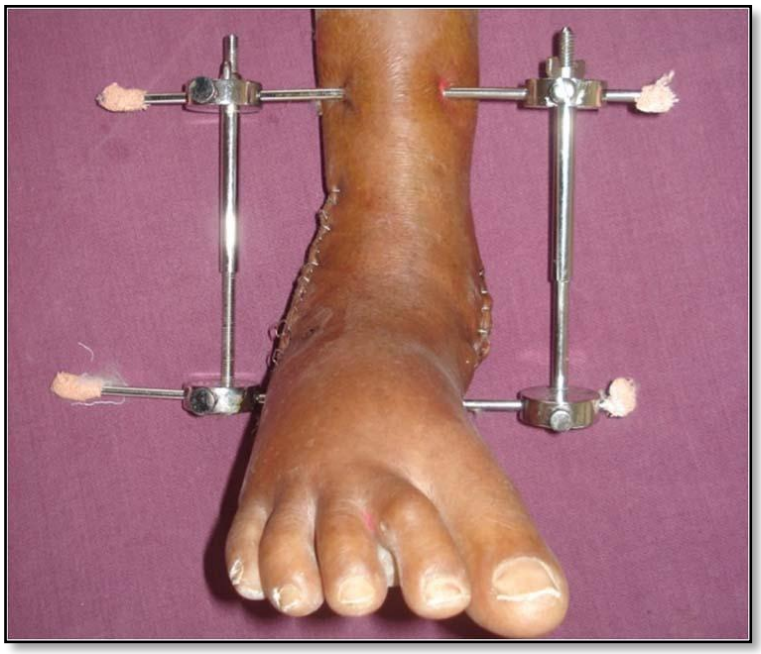

Figure 3: Clinical photo showing Charnley's compression device. (19)

Figure 4: Xray photo showing Charnley's compression device. (19)

3-Circular External Fixation (Ilizarov-Type Fixation)

Circular external fixation, with the Ilizarov construct representing its most prevalent form, is the predominant and most adaptable external fixation technique employed in ankle arthrodesis. The system comprises tensioned transosseous wires secured to rings, which are interconnected by threaded rods, thereby providing rigid multiplanar stabilization. Its principal advantages include superior three-dimensional stability, the capacity to apply precise, controlled compression at the arthrodesis site, and the ability to perform gradual deformity correction post-operatively.

Furthermore, it facilitates early protected weight-bearing and obviates the need for permanent internal hardware, which is particularly advantageous in the presence of active or prior infection. Notable limitations are its technical complexity, the requisite extended period of frame application, a predisposition to pin-tract infections, and challenges related to patient tolerance and adherence. Despite these constraints, numerous clinical series document consistently high union rates associated with circular fixation, especially in the context of complex deformities and compromised patient populations.(5)

Figure (5): ankle arthrodesis by illizarov fixator (4)

4-Hexapod Circular External Fixation (Taylor Spatial Frame)

The Taylor Spatial Frame (TSF) is a computer-assisted hexapod external fixation system based on Ilizarov principles, allowing precise multiplanar deformity correction through software-guided strut adjustments. Its advantages include high correction accuracy, postoperative adjustability without further surgery, and strong structural stability, while limitations involve higher cost, a steep learning curve, and reliance on patient compliance; nevertheless, it remains a valuable option for staged ankle arthrodesis and complex peri-ankle deformity correction (Figure 6).(4)

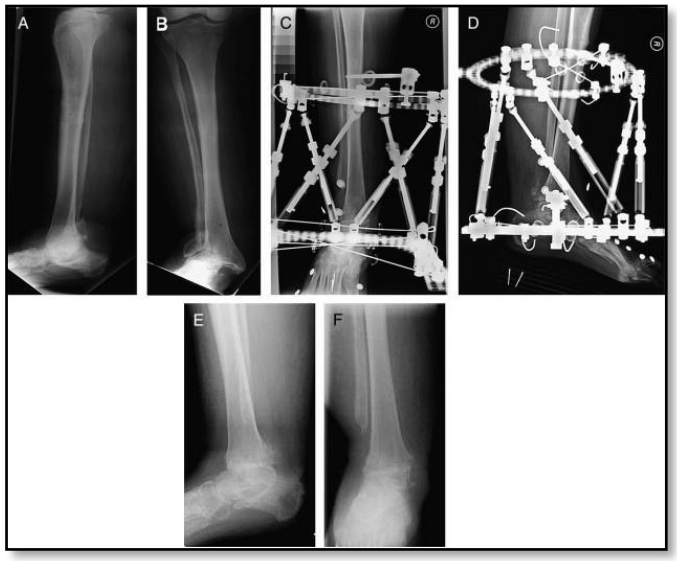

Figure (6): Taylor Spatial Frame (20)

5-Hybrid External Fixation

Hybrid external fixation is a surgical technique that integrates components of circular and monolateral fixation systems. This construct typically employs rings or partial rings for distal tibial fixation, combined with proximal half-pin anchorage. Its primary mechanical advantages include enhanced stability relative to standard monolateral fixators and a lower profile compared to traditional full circular frames. However, the system presents certain limitations. Notably, it offers less versatility and a more restricted capacity for complex multiplanar deformity correction than complete circular external fixation systems.(9)

Surgical Techniques of External Ankle Arthrodesis

1. Pre-operative Planning

Successful ankle arthrodesis utilizing external fixation necessitates meticulous preoperative planning. This process comprises four principal components. First, a thorough assessment of indications must be conducted, with key considerations including active infection, Charcot neuroarthropathy, severe deformity, poor bone stock, and prior failed internal fixation. Second, comprehensive imaging is required.

This protocol should consist of weight-bearing anteroposterior, lateral, and mortise radiographs, supplemented by a computed tomography scan to evaluate bone loss, deformity, and nonunion. Magnetic resonance imaging is indicated if infection or avascular necrosis is suspected. Third, appropriate fixator selection is critical, with options including a monolateral fixator, a circular (Ilizarov) fixator, or a hexapod frame (e.g., Taylor Spatial Frame). Finally, definitive alignment goals must be established prior to surgery. These objectives universally target neutral dorsiflexion, 0 to 5 degrees of hindfoot valgus, slight external rotation, and a plantigrade foot position.(5)

2. Patient Positioning and Preparation

Standard positioning and preparation are essential for ankle arthrodesis, with the patient placed supine; tourniquet use is optional but contraindicated in suspected infection, intra-operative fluoroscopy is mandatory, and peri-operative antibiotics should be culture-guided when infection is suspected.(7)

3. Surgical Exposure and Joint Preparation

Several established surgical approaches are utilized for ankle arthrodesis. The anterior approach is the most frequently employed. The transfibular approach is often selected in the setting of post-traumatic arthritis. A minimal open approach or arthrotomy may be used when the procedure is combined with the application of circular external fixation frames.

The technical sequence for joint preparation follows a standardized protocol. First, the articular cartilage is completely resected from both the tibial plafond and the talar dome. Subsequently, sclerotic subchondral bone is excised until viable, bleeding cancellous bone is exposed. Deformity correction is achieved at this stage, typically through precise bone resection or with an adjunctive osteotomy if required. Finally, the prepared bone surfaces are perforated with multiple drill holes to augment the local biology for fusion.(9)

Clinical Indications for External Ankle Arthrodesis

External fixation serves as a definitive modality for ankle arthrodesis in complex cases where internal fixation is contraindicated or prone to failure. Primary indications include Charcot neuroarthropathy characterized by compromised bone quality. This approach is further necessitated by severe malalignment exceeding 10–15°, limb length discrepancies, or tenuous soft-tissue envelopes with impaired vascularity. Additionally, external fixation is indicated for revision surgery following failed internal fixation nonunions and in osteoporotic or neuropathic bone where structural integrity precludes stable screw purchase.(8)

Advantages of External Fixation

External fixation offers several distinct advantages for achieving ankle arthrodesis. Its primary benefit is the minimization of internal hardware, which consequently reduces the risk of surgical site infection and makes it an excellent option for arthrodesis in actively infected fields. The construct allows for gradual correction of

deformity and enables adjustable compression to be applied postoperatively. Furthermore, it often facilitates early, protected weight-bearing in the postoperative period. This technique preserves existing bone stock and is biomechanically effective even in the presence of poor bone quality.(4)

Disadvantages and Complications

External fixation entails several clinical disadvantages and complications, primarily a high incidence of superficial pin-tract infections and significant patient intolerance due to frame-related morbidity and functional interference. The technique demands a steeper surgical learning curve and introduces the risk of iatrogenic neurovascular injury during wire placement. Furthermore, evidence suggests that external stabilization may be associated with delayed radiographic and clinical union in specific patient populations. (21)

Contraindications

Contraindications for external fixation include patient noncompliance and severe psychiatric illness, both of which undermine postoperative protocol adherence. Pathophysiological factors, specifically severe peripheral vascular disease, significantly elevate risks of impaired wound healing. Furthermore, the procedure is contraindicated in patients unable to perform essential frame maintenance or those lacking consistent access to long-term clinical follow-up, which is requisite for monitoring and complication management. (6)

Outcomes and Union Rates

Reported union rates for external fixation in ankle arthrodesis range from 80% to 95%, a variation contingent upon patient selection and surgical indication. In cases involving Charcot neuroarthropathy or active infection, external fixation demonstrates superior limb salvage outcomes relative to internal fixation techniques. Several studies indicate that fusion rates achieved with external fixation are comparable to those of internal fixation, with external fixation conferring specific advantages in high-risk patient cohorts. (3)

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