



JOURNAL OF THE

Foot & Ankle

Volume 20, Issue 2, May-August





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**CAIO NERY, M.D. |**

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Five years by the numbers: What an independent bibliometric study tells us about the Journal of the Foot & Ankle

In this issue, a group from Duke University School of Medicine, led by Julieta Brué and senior author Cesar de Cesar Netto, publishes the first bibliometric analysis of the Journal of the Foot & Ankle (JFA) since its 2020 reformulation⁽¹⁾. An outside team choosing to examine our journal's output in such detail is itself a form of recognition, and the picture it draws is one we are glad to share with our readers, authors, and reviewers.

Between January 2020 and December 2025, JFA published 334 peer-reviewed research articles, averaging 56 per year and rising to 73 in 2025 alone – a trajectory of sustained, accelerating growth. Original articles accounted for nearly 70% of that output, and the share of systematic reviews and other higher-evidence document types has been increasing, a shift that reflects the growing methodological maturity of the manuscripts we receive. More than a thousand unique authors, a mean of 5.2 per article, have contributed to this body of work, evidence of the collaborative culture our specialty has built around the journal.

Geographically, the study confirms what our editorial board has long understood: JFA is a Brazilian-anchored but genuinely Ibero-American journal. Brazil accounts for 55.4% of articles, with meaningful contributions from Argentina, the United States, Spain, Chile, Mexico, Portugal, and Colombia. International collaboration, present in 10.5% of articles and reaching 14.3% in some years, shows this regional identity is not insular – it is a platform from which our authors engage the wider foot and ankle community. The authors note, and we find it worth underlining, that only 2.62% of editorial board seats across major international foot and ankle journals are held by researchers from Latin America and the Caribbean. Against that backdrop, a journal with fully regional editorial governance, authorship reach across a dozen countries, and a leadership ranking spanning Brazil, the United States, Argentina, and South Africa is not a peripheral outlet. It is infrastructure for our specialty.

The citation analysis – 272 accumulated citations and a journal h-index of 6 – is, understandably, the most modest of these findings, and we present it as exactly what it is: the early footprint of a young, not-yet-indexed journal. Indexation status, more than study quality itself, is among the strongest predictors of citation accrual, and citation lag in medical publishing typically runs six to eight years; more than half of the articles counted here were published in 2024 or later, so the clock on most of our recent output has barely started. The data show the raw material for growth: rising volume, rising rigor, and a Diamond Open Access model that removes cost as a barrier to publishing and reading alike – a model few regional journals sustain and one that has become a defining part of our identity.

We are highlighting this study now because 2026 is the year JFA is pursuing indexation in SciELO. Bibliometric self-knowledge is a precondition for that process, not a substitute for it, and this independent analysis gives the journal, its editorial board, and the evaluating committees a transparent, reproducible



account of five years of production, authorship, geographic reach, and citation behavior – exactly the evidence a journal is asked to produce when it applies.

We are grateful to Brué, Micicoi, Rodrigues, Umrethiya, Rachayont, Pozzessere, and de Cesar Netto for undertaking this work rigorously and for choosing to publish it with us. None of the numbers above are the achievement of an editorial

office alone – they belong to the surgeons and researchers who have trusted JFA with their work, to our unpaid reviewers, and to the ABTPé and FLAMeCIPP communities that sustain its Diamond Open Access mission. As we move toward SciELO indexation, our commitment remains the one this study describes: a journal that lowers barriers, preserves regional research leadership, and continues to raise the evidentiary bar of what it publishes.

Reference

1. Brué J, Micicoi L, Rodrigues V, Umrethiya V, Rachayont K, Pozzessere E, de Cesar Netto C. Five-year bibliometric analysis of the Journal of the Foot & Ankle (2020-2025). J Foot Ankle. 2026;20(2):e2132.

Special Article

Total ankle arthroplasty in younger patients: Current concepts, contemporary evidence, and decision-making considerations

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Abstract

This article reviews the current evidence on total ankle arthroplasty (TAA) in patients younger than 55 years, including recent clinical outcomes and technical considerations, through a comparative analysis that underscores the areas of greatest controversy in its application. It is highlighted that, although in this group of patients there are higher rates of revision and re-operation, compared to older patients, the current evidence of TAA with state-of-the-art implants shows an acceptable survival in the medium term even in cohorts with young patients, indicating that, although age may be a risk modifier, it is not in itself an absolute contraindication. Rigorous patient selection and precise alignment are determinants, while prosthetic design and proper deformity correction significantly influence outcomes.

Level of Evidence V; Narrative Review, Expert Opinion.

Keywords: Total ankle arthroplasty; Ankle replacement; Young patient; Implant survivorship; Complications; Biomechanics.

Introduction

Ankle arthrosis (AA) is a disabling disease whose management was initially limited to tibiotalar arthrodesis, with disadvantages including functional loss of the ankle, morbidity of neighboring joints, and complications inherent to the procedure. For its part, the TAA has evolved significantly in the last two decades. First- and second-generation prostheses were reserved for patients with low functional demand and advanced age, whereas they are proposed more frequently for younger, more active individuals.

Overall prosthetic survival has shown encouraging results, with cumulative rates of 85%-90% at 10 years in the general population. However, direct extrapolation to patients under 55 should be made with caution, given their higher activity levels and longer prosthetic life expectancy. This article critically reviews contemporary evidence on TTA in adults

under 55, integrating recent clinical outcomes, comparative analyses, and technical considerations, with an emphasis on controversy.

Theoretical framework

Anatomy

The articular surface of the distal tibia has a longitudinal convexity that coincides with a concavity in the surface of the talus. The center of coincident convexity and concavity divides the tibiotalar joint into the medial and lateral compartments, which are important when assessing ankle weight-bearing and degenerative changes. The bony and ligamentous anatomy of the ankle joint confers a high degree of stability and congruence, protecting the articular cartilage from shearing forces⁽¹⁾.

Study performed at the Santa Ana Medical Center, Bogotá, Colombia.

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A stable ankle is the result of a static interaction (bones, ligaments, retinaculum) and dynamic (muscles, tendons) anatomical structures. The movement course within the ankle joint is predominantly from plantar flexion to dorsiflexion. Additionally, it performs internal and external rotation movements. Under weight-bearing conditions, the congruence of bone structures provides 100% of the stability for eversion and inversion, but only 30% of the rotational stability, while the ligament component participates by controlling the remaining 70% and all of the anterior-posterior tibiotalar displacement⁽²⁾.

The total area of the tibiotalar joint is approximately 350mm² and is subject to an axial force of ~ 500 N, compared to the hip and knee, which, with joint areas of 1,100mm² and 1,120mm² respectively, are subject to the same amount of force, thus indicating that the pressure on the ankle joint cartilage can be up to three times that of other joints of the lower limbs^(3,4).

The articular cartilage of the ankle has an approximate thickness of 1-1.62 mm, much smaller compared to that of the knee, which is approximately 1.69-2.5 mm. It also has unique characteristics, including more cross-linked glycosaminoglycans and fewer collagenase and interleukin (IL)-1 receptors (IL-1R) than other types of articular cartilage, providing high stiffness and tensile strength⁽³⁾.

Ankle osteoarthritis

Osteoarthritis involves progressive thinning of the hyaline cartilage layer, increasing mechanical stress within the cartilage matrix and reducing the tissue available to withstand joint loads. This results in a spiraling cycle of degeneration, whereby aberrant mechanical feedback drives a chronic and pathological remodeling process that accelerates the progression of AA⁽²⁾. Figure 1 shows the terminal arthrosis of the left ankle in a 44-year-old female patient is presented as a sequel to an astragalus fracture, Hawkins III.

Globally, various classification schemes for ankle osteoarthritis are frequently used in medical practice to guide diagnosis⁽³⁾. Tables 1 to 3 present the most widely used and are generally based on a description of four stages according to the evolution of joint involvement.

Epidemiology of ankle osteoarthritis in younger patients

Approximately 15% of the global adult population is affected by joint pain and disabilities resulting from osteoarthritis, and approximately 1% has ankle osteoarthritis⁽⁴⁾. Ankle arthrosis has a prevalence of 47.7 cases per 100,000 inhabitants, with a representation of the annual consultation of 50,000 cases with symptomatic osteoarthritis in the United States, generating a social impact that compares to that of end-stage renal disease or congestive heart failure^(5,6).

In 75%/80% of AA cases, there is a history of a traumatic event (Figure 2); of these, 62% are related to fractures around the ankle and 16% to chronic ligament instability, especially that involving the lateral ligament complex of the ankle; 13% of cases have their origin in secondary causes such as inflammatory arthropathies, hemochromatosis, hemophilia, or osteonecrosis; and only 9% of patients have primary osteoarthritis, which differs from what is evident in the hip and knee^(3,4,7).

Consistently, in 2005, Saltzman et al.⁽⁶⁾ reported that the origin of ankle osteoarthritis is 70% post-traumatic, 12% rheumatoid disease, and 7% idiopathic (primary osteoarthritis). In addition, they explained that AA is due to an alteration in the relationship between the load exerted on the articular surfaces in the presence of joint incongruity and the instability resulting from soft tissue injuries, with a predictable progression in three stages: stage I: increased contact stress with joint damage, stage II: chondrocyte response to alteration and rupture of the extracellular matrix and stage III: failure of the chondrocyte response.



Figure 1. Anteroposterior, lateral and mortise views showing end-stage osteoarthritis of the left ankle.

Table 1. Takakura classification

Stage	Radiographic signs of osteoarthritis
Stage 1	No joint space narrowing, but early sclerosis and osteophyte formation.
Stage 2	Medial joint space narrowing.
Stage 3	Obliteration of the joint space with medial subchondral bone contact.
Stage 4	Obliteration of the entire joint space with complete bone-on-bone contact.

Table 2. Ankle osteoarthritis classification system (as suggested by Giannini et al.)

Stage	Radiographic signs of osteoarthritis
Stage 0	Normal joint space or subchondral sclerosis.
Stage 1	Presence of osteophytes without joint space narrowing.
Stage 2	Joint space narrowing with or without osteophytes.
Stage 3	Subtotal or complete disappearance or deformity of the joint space.

Table 3. COFAS classification system for end-stage ankle osteoarthritis (as suggested by Krause et al.)

Type	Description
Type 1	Isolated ankle arthritis.
Type 2	Ankle arthritis with intra-articular varus or valgus deformity, tight heel cord, or both.
Type 3	Ankle arthritis with hindfoot deformity, tibial malunion, midfoot abduction or adduction, midfoot supination, plantarflexed first ray, etc.
Type 4	Type 1 to 3 findings plus involvement of subtalar, calcaneocuboid, or talonavicular osteoarthritis.

On the other hand, Soyoung Lee et al. (8), in 2022, in their study conducted in South Korea, found that women with sprains and obese individuals had a 40% higher risk of developing ankle osteoarthritis. Additionally, they reported that age greater than 65 years and exercise were not significant risk factors for the diagnosis of AA in patients with compromised status.

A recent epidemiological study evaluating nearly 200,000 patients with ankle sprain demonstrated a significant association with later development of osteoarthritis, underscoring the cumulative burden of micro instability and chondral damage⁽⁶⁾. The predominantly post-traumatic etiology tends to affect a younger patient population, between 18 and 44 years of age, than those with other degenerative joint diseases in the lower limbs^(4,7). This explains why a relevant proportion of definitive surgical candidates are in the fifth decade of life. Contemporary analysis of therapeutic algorithms for AA recognizes that isolated chronological age is no longer an absolute criterion for ruling out TAA⁽⁷⁾.



Figure 2. Radiological image of the left ankle in a 29-year-old female patient with a Hawkins III talus fracture. (A) Anteroposterior, lateral, and mortise views of the fracture (B) Anteroposterior and mortise views of the ankle, and anteroposterior view of the foot, comparative.

Paradigm shift: from arthrodesis to TAA

Historically, AA has been considered the gold standard for younger patients, as it offers predictable results and a lower rate of long-term reintervention compared with TAA. However, long-term follow-up demonstrated that arthrodesis alters hindfoot kinematics and increases mechanical loads in adjacent joints, particularly in the subtalar and midtarsal joints. This results in progressive secondary degeneration and eventual need for additional procedures⁽⁹⁾.

On the other hand, the evolution of prosthetic design, anatomical designs, resurfacing technique (minimal bone sacrifice), biocompatible surfaces, osseointegration by porous coatings, fixed inserts, and use of biomaterials with lower friction torque, innovations in surgical technique that enable more precise prosthetic implantation, and patient-specific prosthetic design have improved clinical results and reduced the rate of early catastrophic failures reported in first- and second-generation prostheses.

Currently, TAA offers the advantage of preserving mobility, allowing a more physiological gait pattern, and protecting adjacent joints. These are especially relevant factors in patients with long functional life expectancy.

Ankle prosthesis

In 1962, an ankle joint “hemiarthroplasty” was performed on a 31-year-old male patient using a custom talar dome-covering implant made of Vitallium (a biocompatible cobalt-

chromium-molybdenum alloy). The procedure was performed by Carrol Larson, who applied the concept of “cup arthroplasty” of the hip to the ankle, popularized at the time by his mentor, Smith-Petersen. Larson implanted a talar dome replacement prosthesis using a lateral approach⁽⁹⁾.

For its part, the first TAA was practiced by Lord and Marrotte in 1970. Its prosthesis could be described as an “inverted hip”, with a long-stemmed metal component implanted in the tibia, which articulates with an acetabular cup cemented in the calcaneus, after having completely extracted the talus^(9,10).

First-generation prostheses did not fully account for the anatomy and biomechanics of the ankle, thereby imposing excessive or insufficient restrictions. These were two-part systems with a concave articular surface of polyethylene and a convex surface of metal with chromium-cobalt alloys. In most cases, the polyethylene component was adapted to the tibial component, while the talar component was made of metal. In all cases, the technique was supplemented using bone cement. These prostheses showed promising initial results but had high failure rates after two years, so the technique was abandoned for almost a decade^(10,11).

In the case of second-generation prostheses, new implants were designed with special attention to replicating normal ankle anatomy, joint kinematics, ligament stability, and mechanical alignment, using semi-constrained devices and avoiding the use of cement⁽¹⁰⁾.

In the early 1990s, designs more closely replicated the natural anatomy of the ankle, showing better clinical outcomes, improving implant designs, featuring mobile inserts, and less constriction, resulting in gradual improvement, with survival rates of approximately 80% at 10 years^(9,10).

The three-component prosthesis consists of two metal components: one in the talus and one in the tibia, separated by a “mobile meniscus” of ultra-high molecular weight polyethylene, which provides a movement with low contact effort, while allowing inversion and eversion⁽⁹⁾.

The third- and fourth-generation prostheses focus on customized components and better anatomical adaptation; additionally, fourth-generation prostheses aim to perform a smaller bone resection.

The Infinity® Ankle Prosthesis (Stryker) is a state-of-the-art bicomponent ankle prosthesis widely used in the United States; it is characterized by minimal bone resections (Figure 3), small tibial fixation pegs and talar (PEG) that avoid the use of long stems, uncemented technique, and an anatomical component of the talus that reproduces the geometry of the native talus⁽¹²⁾ (Figure 4). For its part, a study by Shaferry et al. with a 6.5-year (5-8 years) follow-up demonstrated a 93.8% survival rate for the Infinity® prosthesis⁽¹³⁾.

The Inbone® ankle prosthesis (Stryker) has been used since 2005, with a survival rate of 90.3% at 5 years⁽¹⁴⁾. It is a modular intramedullary tibial stem device that allows the addition of components to increase its length, a logging component, and a polyethylene insert in a saddle distribution.

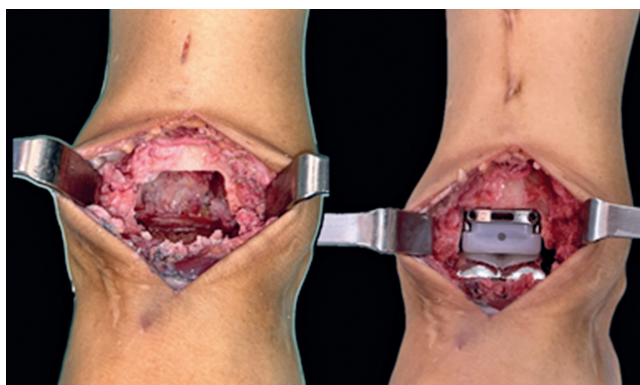


Figure 3. Infinity® prosthesis implantation.

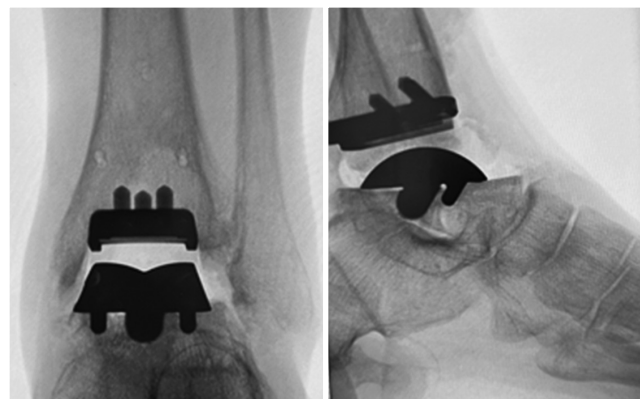


Figure 4. Post-operative radiological image of total ankle arthroplasty, Infinity® prosthesis.

For implantation, a support is used to firmly fix the limb and to allow orthogonal cuts in the sagittal and coronal planes, with alignment achieved during insertion using fluoroscopy. Its design allows its use for both primary replacements in cases of severe deformities, tibial bone loss, or distal tibial infarction, and revision surgeries⁽¹⁵⁾. In the Inbone II® version, greater modularity of the tibial component was added, two anterior PEGs were introduced into the talar component, and a central groove-shaped talar design was implemented. Gagne et al., in their study in 2021, demonstrated a survival rate of 98% at 5 years⁽¹⁶⁾.

Ankle prosthesis in younger patients

The number of TAAs in younger patients is increasing, and their indications have expanded over time due to improved design and growing evidence of their use. It must be considered that multiple variables, including patient characteristics, influence their outcome⁽¹⁷⁾.

Historically, it has been proposed that the ideal patient for a TAA is a physically undemanding patient, not obese, older, with non-traumatic primary ankle osteoarthritis in the terminal stage or multiple joint arthritis with minimal deformity, good bone reserve, without neurovascular deterioration of the leg and with more than two-thirds of the normal range of motion of the ankle.

Regarding the indication for TAA in younger patients, great caution has been taken, given that implant longevity may be affected by functional requirements and long-term expectations, which are directly proportional to life expectancy. In addition, younger patients tend to be more active, which can lead to faster wear of the implant. Additionally, special attention should be paid to patients with inflammatory joint disease, since they are younger at the time of implantation but are often less active because multiple joints are affected⁽¹⁷⁾.

In 1999, Kofoed and Lundberg-Jensen published the results of 100 uncemented STAR prostheses, 30 of which were implanted in patients under 50 years, with a survival of 75% at 6.8 years, and 70 in patients over 50 years, with a survival of 81% at six years, indicating the absence of a statistically significant difference between the two groups⁽¹⁸⁾.

In 2013, Rodríguez-Pinto et al.^(19,20), evaluated ankle prostheses in 31 patients under 50 years versus 72 patients over 50 years, at a 40-month follow-up, finding a significant increase in AOFAS scores, postoperative gains in mobility ranges, and a tendency toward fewer minor complications in the group of patients under 50 years.

In 2015, in a cohort of 395 patients divided into 3 age groups (< 55, 55-70, and > 70 years), they found that patients younger than 55 years had greater improvements in AOFAS vitality and function scores than those older than 70 years. They found no differences in pain, physical performance outcomes, or incidence of wound complications or need for reoperation or revision⁽²¹⁾.

In a 2020 meta-analysis, 10 articles were evaluated, including 1963 implants that met the inclusion criteria. They found that overall implant survival was 86.5%. Using a median age of 62.65 years, they reported a survival rate of 95.5% in studies above the median and 90.3% in studies below it, although this association was not statistically significant⁽²²⁾.

In 2022, Cottom et al.⁽²³⁾ reported a series of 112 cases of ankle prostheses divided into three age subgroups: Group 1: < 55 years, Group 2: 55-70 years, and Group 3: > 70 years, showing improvement in the AOFAS score and the Foot Function Index (FFI); no statistically significant difference was found regarding complications.

However, post-traumatic ankle osteoarthritis usually presents at a much younger age, and although TAA has traditionally been recommended for older and less physically demanding patients, it has been shown that patient satisfaction remains high, even in younger populations with higher functional demand and probably higher postoperative expectations^(17,23).

Biomechanics and specific considerations of the younger patient

The survival and behavior of a prosthesis in younger patients represents a biomechanical challenge different from that of older patients, considering the level of physical activity with greater intensities and a greater number of load cycles over time (cumulative load), a greater expectation of prosthetic survival, and deformities frequently associated with a post-traumatic etiology.

However, from a biological and functional perspective, the improved baseline musculoskeletal status of this age population could contribute to more efficient rehabilitation and potentially to greater functional durability of the implant. This considering that in general the younger patient presents better bone quality, better muscle condition, greater functional reserve, more effective gait patterns, less proprioceptive and balance commitment, which translates into a better ability to restore joint kinematics after TAA, obtaining a better response in relation to parameters such as cadence, step length and gait speed and reflecting a relevant functional recovery, with symmetry in gait and joint mechanics.

Functional demands: Patient, under 55 years of age, usually maintains a demanding occupational activity and participates in recreational sports. Repeated exposure to high cyclic loads may accelerate polyethylene wear and micromotion-related loosening. In addition, young patients have a higher expectation of returning to impact activities, which requires a clear preoperative discussion of realistic limitations.

Prosthetic load and survival: Mechanically, TAA survival depends on proper coronal alignment, ligament balance, bone quality, and homogeneous load distribution. In younger patients with post-traumatic residual deformity, the risk of eccentric overload increases if the correction is not anatomical.

Ligament alignment and balance: Neutral or slightly valgus alignment is critical. Residual varus greater than 5° is associated with increased risk of tibial loosening. In younger patients with significant structural deformity, TAA should be combined with corrective osteotomies and ligament reconstruction when necessary.

Clinical outcomes and prosthetic survival

Contemporary discussion of TAA in younger patients should be supported by evidence specific to this age group. A comprehensive meta-analysis published in 2020 on global prosthetic survival demonstrated cumulative survival rates close to 85%-90% at 10 years in the general population⁽²²⁾. However, this analysis predominantly included older patients, limiting direct extrapolation to those under 55 years.

When younger patients are specifically analyzed, the evidence becomes even more nuanced. A 2020 study on total ankle replacement in young patients reported significant

functional improvement but also a higher rate of reoperation compared with older cohorts; in the meantime, they will avoid progressive degeneration of adjacent joints⁽²⁴⁾. This finding suggests that while the clinical benefit is real, the cost in terms of reinterventions is not negligible.

More specifically, a 2021 study that evaluated survival, complications, and revision rates in patients younger than 55 years included 51 patients, with a mean age of 49.4 years, a mean weight of 93kg, and a mean follow-up of 31.2 months. There were seven major complications (13%) that required a return to the operating room. These included two surgical wound dehiscences, two talar component subsidences, two deep joint infections, and one flexor hallucis longus tendon injury. Overall implant survival was 94%, and only three patients required explantation. There were eight minor complications (15%) that resolved with conservative treatment. Nonetheless, medium-term survival rates remained clinically acceptable, reinforcing the need for interpretation and contextualization rather than absolute conclusions⁽²⁵⁾.

More recently, an intermediate follow-up study in patients ≤ 50 years published in 2024, with a follow-up of 8.8 years in 58 patients, showed that functional results can be satisfactory in the medium term; 11 patients presented complications related to arthroplasty, and only one patient required revision of the metal components of the prosthesis, which evidenced a survival of the implant of 98% at 8.8 years⁽²⁶⁾. This reinforces the concept that TAA in younger patients is not synonymous with early failure, but does imply a higher cumulative likelihood of reoperation.

A 2024 systematic review by Kipp et al.⁽²⁷⁾ failed to demonstrate statistically significant differences between younger (≤ 50 years) and older patients in terms of reoperation rate (RR 1.24; $p = 0.412$), complications (RR 1.01; $p = 0.955$), and implant survival (RR 1.04; $p = 0.155$). From a clinical perspective, this work questions the traditional paradigm that restricted TAA to older patients with low functional demand, supporting a cautious expansion of indications towards younger patients.

Current indications and contraindications

- **Deformity:** Severe deformity is not an absolute contraindication, but it increases the technical complexity and risk of reintervention.
- **Instability:** Concomitant ligament correction is critical to avoid early failure.
- **Avascular necrosis:** Careful selection is essential, particularly in advanced talar collapse.
- **Obesity and occupational activity:** Recent evidence suggests that greater physical activity may be associated with higher complication rates.

Surgical technique

For proper implantation, it must be considered that weight-bearing radiographs are mandatory, an evaluation of the hindfoot must be conducted, during implantation, it is essential to perform the complete correction of the deformity in both varus and valgus, oversizing of the components must be avoided, and a meticulous ligament balance must be performed.

Future direction

- Navigation
- Custom implants
- Improvements in biomaterials

Conclusion

Total ankle arthroplasty in patients younger than 55 years should not be discounted on the basis of chronological age. Contemporary evidence increasingly demonstrates improved medium-term prosthesis survival and functionally significant improvements for patients. However, these patients are at consistently higher risk of revision and complications. The key is not the age itself, but the biomechanical environment, proper deformity correction, accurate implant selection, and realistic targeting of expectations by the surgeon. In expert hands, TAA is a carefully selected, valid strategy for preserving mobility in younger patients.

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Special Article

Hallux rigidus

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Abstract

Hallux rigidus is a common disorder with a multifactorial etiology and is highly disabling in many cases. Factors associated with the condition include trauma, particularly in cases of unilateral involvement; metatarsophalangeal joint shape; and shortening of the soft-tissue structures of the posterior chain. Some studies have also associated excessive length and elevation of the first metatarsal with the disorder. Conservative treatment may provide temporary symptom relief, especially in the early stages, but cannot eliminate or reduce established degenerative changes. Surgical treatment depends on the patient's characteristics and expectations, as well as the clinical and radiographic stage of the disorder. Joint-preserving procedures, such as metatarsal and proximal phalanx osteotomies, are the preferred approach for less severe grades of the disorder, whereas interposition arthroplasty and arthrodesis are indicated for more advanced disease. When technical indications are followed, most cases expect good to excellent results.

Level of Evidence V; Narrative Revision.

Keywords: Hallux rigidus; Arthritis; Hallux; Hallux limitus; Bunion.

Introduction

Hallux rigidus is the second most common disorder affecting the first ray. Although less prevalent than hallux valgus, it is generally more disabling. It is the most common form of osteoarthritis in the foot and ankle, affecting approximately 2.5% of individuals older than 50 years and occurring twice as frequently in women⁽¹⁻³⁾.

Anatomy

The first metatarsophalangeal (MTP) joint represents a complex synovial articulation formed by the first metatarsal head and the base of the proximal phalanx, with the medial and lateral sesamoids constituting an integral component of its plantar functional unit. This highly specialized articulation withstands substantial loads while providing the mobility required for efficient propulsion during gait. The head of the first metatarsal is convex and asymmetric, being wider on its plantar than its dorsal aspect. Its plantar surface contains a longitudinal central ridge that separates the sesamoid

grooves, which articulate with the medial and lateral sesamoid bones. The concave geometry of the proximal phalangeal base conforms to the convex metatarsal head, allowing articular motion while maintaining congruence. Plantarly, the paired sesamoids are incorporated within the flexor hallucis brevis tendon and articulate with the grooves along the inferior aspect of the metatarsal head. The sesamoid complex contributes to the distribution of plantar forces across the first ray and enhances the mechanical efficiency of the flexor mechanism. Its articulation with the plantar ridge contributes to joint stability and resistance to coronal plane deformity. The joint capsule is relatively lax dorsally and thicker on the plantar aspect, where it merges with the plantar plate. The collateral, metatarsosesamoid, intersesamoid, and phalangeosesamoid ligaments provide stability and maintain joint alignment during gait and other weight-bearing activities. Dynamic control of the first MTP joint is provided primarily by the flexor hallucis longus and brevis and the extensor hallucis longus and brevis. The flexor hallucis brevis divides into medial and lateral components

Study performed at the Moinhos de Vento Hospital, Porto Alegre, RS, Brazil.

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associated with the respective sesamoids. Together, these structures provide active hallux motion and play a critical role in propulsion during gait⁽¹⁻⁴⁾.

Pathologic anatomy

Hallux rigidus appears to arise from the interaction of multiple predisposing factors rather than from a single identifiable cause, including anatomic configuration, traumatic events, and hereditary predisposition, which may collectively influence disease onset and progression. A positive family history has been reported in approximately two-thirds of patients, whereas bilateral involvement is present in up to 79% of cases⁽¹⁻³⁾. Coughlin and Shurnas⁽⁴⁾ observed that hallux rigidus was unilateral in 78% of patients with a history of trauma.

Structural factors associated with hallux rigidus include the morphology of the first metatarsal head, contracture of the gastrocnoleus complex, metatarsus primus elevatus, an excessively long first metatarsal, and metatarsus adductus⁽⁴⁾. A flat or triangular first metatarsal head increases resistance to coronal plane deformity, particularly hallux valgus, but also concentrates axial loads, thereby predisposing the joint to first MTP osteoarthritis⁽¹⁻⁴⁾.

Contracture of the gastrocnoleus complex reduces sagittal plane mobility and increases dorsal loading across the first MTP joint, thereby promoting progressive cartilage degeneration. Hallux limitus, also referred to as functional hallux rigidus, represents an early stage of the disorder in which restricted dorsiflexion results primarily from increased tension in the plantar soft tissues, particularly the gastrocnoleus complex and the plantar fascia. On clinical examination, the limitation in dorsiflexion is characteristically more pronounced with the ankle in dorsiflexion and improves substantially with ankle plantarflexion, reflecting relaxation of the plantar soft tissues⁽⁵⁻⁸⁾.

The association between metatarsus primus elevatus and hallux rigidus remains controversial, as several studies have failed to confirm this relationship⁽⁹⁻¹²⁾. One major limitation is the lack of a standardized method for assessing first metatarsal elevation across studies. Some investigators have measured its height relative to the ground, others relative to the second metatarsal, and still others relative to the proximal phalanx of the hallux. This methodological heterogeneity complicates comparisons among studies and limits interpretation of the available evidence⁽⁹⁾. Whether metatarsus primus elevatus represents a primary deformity predisposing to hallux rigidus or a secondary consequence of the disease also remains debated⁽⁹⁻¹²⁾. Fukushima et al.⁽¹¹⁾ compared first-ray elevation using weight-bearing computed tomography in 18 patients (21 feet) with early-stage hallux rigidus and 10 healthy volunteers (19 feet). Sagittal images demonstrated narrowing of the dorsal joint space and a more plantar location of the center of rotation in patients with hallux rigidus than in controls. These differences became progressively more pronounced with advancing disease severity. Based on these findings, the authors proposed

that failure of the windlass mechanism occurs early in the disease process, resulting in progressive elevation of the first metatarsal⁽¹¹⁾. Additional evidence suggests that metatarsus primus elevatus may improve following surgical treatment, even in the absence of a plantarflexion osteotomy of the first metatarsal. In a study of 27 patients who underwent implant-free interpositional arthroplasty, Sanchez et al.⁽¹³⁾ found that first metatarsal elevation was more common in advanced stages of hallux rigidus and concluded that it was more likely a consequence than a cause of the disorder. Similarly, Horton et al.⁽¹⁰⁾ compared lateral radiographs from 81 patients with hallux rigidus, 50 asymptomatic volunteers, and 64 patients with isolated Morton's neuroma. Mean first-ray elevation was virtually identical in patients with mild or moderate hallux rigidus and in asymptomatic controls, whereas patients with advanced radiographic disease exhibited only a modest increase in metatarsus primus elevatus.

Although Coughlin and Shurnas⁽¹⁴⁾ found no difference in first metatarsal length between patients with hallux rigidus and the general population, Calvo et al.⁽¹⁵⁾ reported contrasting findings in a case-control study involving 132 feet treated surgically for hallux rigidus (72 patients) and 132 control feet (66 healthy volunteers). They observed that the first metatarsal was significantly longer in patients with hallux rigidus than in controls.

Pathophysiology

Adequate first MTP joint mobility is essential for normal propulsion and requires nearly 60° of hallux dorsiflexion during gait. Mechanical demand on the joint increases markedly during push-off, when forces transmitted through this region can reach approximately 1.2 times body weight. Consequently, pain and loss of hallux motion from osteoarthritis alter both gait cadence and the biomechanics of walking and running⁽⁷⁾.

Hallux rigidus is a progressive arthritic condition involving the first MTP joint characterized clinically by progressive pain and loss of range of motion. Unlike osteoarthritis affecting most other joints, restriction of motion typically precedes cartilage degeneration, underscoring the predominant biomechanical component of this condition⁽⁸⁾. Joint motion is closely coordinated with the windlass mechanism, in which hallux dorsiflexion tensions the plantar fascia and elevates the medial longitudinal arch, thereby increasing structural rigidity and creating a stable platform for push-off. Under physiological conditions, hallux dorsiflexion depends on coordinated rolling and gliding of the proximal phalanx over the first metatarsal head, allowing efficient load distribution during gait⁽¹⁻⁸⁾.

Functional hallux rigidus

Functional hallux rigidus refers to a dynamic limitation of the first MTP joint, with preserved mobility during unloaded examination but reduced dorsiflexion once weight is transferred through the first ray or the ankle moves into

dorsiflexion (Figure 1). Mechanically, functional hallux rigidus is characterized by a predominance of rolling rather than the normal gliding contact between the articular surfaces.

The windlass mechanism is essential for maintaining the medial longitudinal arch and depends on the coordinated function of an osseous arch that resists compressive forces together with supporting soft tissues that resist tensile forces. Among these structures, the plantar fascia plays the dominant role because of its favorable mechanical lever arm. Elevation of the first metatarsal head and increased tension within the plantar fascia may alter first MTP joint kinematics, resulting in rolling rather than the physiological gliding motion of the articular surfaces.

Restricted dorsiflexion of either the ankle or the first MTP joint limits normal anterior progression of the tibia during the stance phase of gait. This impairment is compensated for by abnormal movements in other planes and adjacent body segments⁽⁶⁻⁸⁾. Contracture of the posterior chain, particularly the gastrocnemius complex and plantar fascia, further disrupts this biomechanical sequence by impairing the synchronized motion between the proximal phalanx and the first metatarsal. Progressive loss of dorsiflexion results in abnormal concentration of compressive forces across the dorsal aspect of the first MTP joint. This process initiates cartilage degeneration, osteochondral irregularities, and progressive joint incongruity, ultimately leading to marginal osteophyte formation, one of the earliest radiographic manifestations of hallux rigidus. These osteophytes contribute substantially to pain and mechanical impingement during dorsiflexion.

Clinically, reduced first MTP joint mobility compromises the propulsive phase of gait, resulting in compensatory

mechanisms such as decreased loading of the first ray and transfer of weight-bearing forces to the lateral border of the foot. In advanced stages, the disease progresses to marked stiffness, extensive cartilage loss, prominent osteophyte formation, and persistent pain, reflecting progressive biomechanical and functional failure of the first MTP joint⁽¹⁻⁸⁾.

Clinical examination

An antalgic gait and limping are common, particularly in advanced disease. During standing examination, the alignment of the hallux and the foot should be assessed, along with dorsal osteophyte formation (dorsal bunion).

Passive mobility of the first MTP joint should be examined with the patient sitting or lying supine, while varying the ankle between neutral alignment and plantarflexion. In an unaffected joint, approximately 75°-90° of dorsiflexion and 20°-30° of plantarflexion can typically be achieved without pain. Changes in hallux mobility associated with ankle dorsiflexion should be carefully assessed, and the Silfverskiöld test should be performed to evaluate gastrocnemius tightness.

During passive range-of-motion testing, the presence and distribution of pain provide important information regarding disease severity. Pain occurring throughout the arc of motion, rather than only at the extremes of dorsiflexion or plantarflexion, is generally indicative of more advanced disease.

Palpation of the dorsal joint line is typically painful and is frequently associated with palpable dorsal osteophytes, depending on disease stage. Osteophyte formation is characteristic of advanced disease and usually begins at the



Figure 1. Lateral view of a foot with functional hallux rigidus. Note the restriction of hallux dorsiflexion with the ankle positioned at 90° (A) and the improvement in hallux dorsiflexion with the ankle in plantarflexion (B).

dorsolateral aspect of the joint, where it further contributes to restriction of joint motion.

Imaging evaluation

Initial imaging should consist of standing foot radiographs obtained in anteroposterior, lateral, oblique and axial sesamoid views. The anteroposterior view is the most appropriate for assessing the metatarsal formula and identifying medial and lateral osteophytes at the level of the first metatarsal head. Joint space width is best evaluated on the anteroposterior and oblique views. The lateral view demonstrates the degree of first metatarsal elevation and the presence of dorsal osteophytes involving the metatarsal head, the proximal phalanx, and the sesamoid complex. The sesamoid axial view is useful for assessing sesamoid involvement, which is common in advanced stages of the disease. Subchondral sclerosis and subchondral cysts involving the first metatarsal head and the base of the proximal phalanx are also common findings and are typically associated with advanced disease.

Computed tomography and magnetic resonance imaging may occasionally provide additional information; however, in most cases, they are unnecessary for therapeutic decision-making.

Classification

Pain severity, range of motion, and radiographic findings are all essential components in assessing the severity of hallux rigidus. Accordingly, the Coughlin and Shurnas⁽¹⁴⁾ classification, the only system that incorporates all three parameters, is currently the most widely used. It comprises five stages, ranging from a peri-arthritis condition to advanced degenerative disease.

Grade 0 represents the earliest stage, with first MTP dorsiflexion remaining between 40° and 60° and showing no more than a 10%-20% reduction relative to the unaffected opposite foot when unilateral disease is present. Standard radiographs reveal preserved joint morphology, without measurable loss of articular space or osteophytes. Patients are asymptomatic, and the only clinical finding is mild restriction of joint motion detected on physical examination.

Grade 1 reflects early structural involvement and is characterized by 30°-40° of dorsiflexion, representing a 20%-50% decrease in physiological motion. The principal radiographic finding is a small dorsal osteophyte, while the articular space remains largely preserved despite subtle narrowing. Minor periarticular sclerosis and early loss of the normal contour of the first metatarsal head may also be present. Symptoms are usually mild and episodic, with slight restriction of motion and discomfort predominantly when the joint approaches the limits of dorsiflexion or plantarflexion.

Grade 2 reflects a substantial decline in first MTP mobility, with dorsiflexion restricted to 10°-30°, corresponding to a 50%-75% decrease in joint motion. Radiographs demonstrate osteophyte formation predominantly along the dorsal and

lateral margins, with medial involvement occurring less consistently. Joint space narrowing is mild to moderate and is accompanied by subchondral sclerosis, whereas the sesamoids are generally preserved. Pain becomes moderate to severe and is often constant, occurring immediately before the extremes of dorsiflexion and plantarflexion.

Grade 3 denotes advanced functional impairment; it is characterized by dorsiflexion of 10° or less, accompanied by a 75%-100% decrease in joint motion. Plantarflexion is also substantially compromised and commonly remains below 10°. Imaging demonstrates pronounced degenerative changes, including substantial loss of articular space and periarticular cyst formation. On lateral radiographs, more than one-quarter of the dorsal joint surface may be affected. Degenerative involvement may also extend to the sesamoid complex which may manifest as enlargement, irregularity, or cystic degeneration. Patients experience severe pain at the extremes of joint motion.

Grade 4 demonstrates radiographic findings similar to those observed in Grade 3; however, patients experience pain throughout the entire arc of passive joint motion rather than only at the extremes of movement.

Despite its comprehensive nature, the Coughlin and Shurnas⁽¹⁴⁾ classification has important limitations. Most notably, it does not account for clinicroadiographic discordance, as radiographic severity does not always correlate with symptom severity or degree of functional impairment. Nixon et al.⁽¹⁶⁾ retrospectively reviewed weight-bearing foot radiographs and Foot and Ankle Ability Measure (FAAM) Activities of Daily Living subscale (FAAM-ADL) scores from 84 patients with hallux rigidus and found no association between radiographic severity and FAAM-ADL scores. Furthermore, progression of radiographic changes was not accompanied by worsening patient-reported symptoms as measured by the FAAM-ADL⁽¹⁶⁾.

Conservative treatment

Early management, especially during the initial stages of the disease, typically consists of footwear modifications to accommodate dorsal osteophytes and reduce mechanical irritation, together with the prescription of orthotic devices to limit dorsiflexion and decrease mechanical loading across the first MTP joint. Rocker-soled footwear is an effective approach to limiting hallux motion during the toe-off phase of gait. Conservative treatment of hallux rigidus should be viewed primarily as a strategy for symptom control and biomechanical optimization rather than as an intervention intended to alter the natural history of the disease, as there is no consensus that nonoperative management can halt its clinical progression⁽¹⁷⁻²⁰⁾.

The available literature suggests that patients with early-stage disease, relatively preserved joint space, and pain predominantly occurring at the end of the dorsiflexion arc are more likely to respond favorably to conservative treatment, whereas those with more advanced disease and greater

structural joint involvement generally achieve less satisfactory outcomes⁽¹⁸⁻²²⁾. The rationale for conservative treatment is to reduce dorsiflexion of the first MTP joint, minimize dorsal impingement between the proximal phalanx and the first metatarsal head, and decrease mechanical irritation caused by dorsal osteophytes against footwear⁽¹⁸⁻²²⁾.

Nevertheless, the evidence supporting conservative treatment remains limited. A systematic review by Kon Kam King et al.⁽¹⁸⁾ found no Grade A recommendation for any conservative intervention. Footwear modification, orthotic devices, and physical therapy were supported only by Grade C evidence, whereas Grade B evidence discouraged routine intra-articular injections⁽¹⁸⁾. Likewise, a systematic review by Munteanu et al.⁽¹⁷⁾, including 547 participants, concluded that the benefits of nonoperative treatment remain uncertain. Although some studies have reported favorable outcomes, larger randomized clinical trials (RCTs) are needed to strengthen the level of evidence and better define indications for conservative versus surgical management⁽¹⁷⁾.

General recommendations for conservative management include activity modification, appropriate footwear, weight reduction when indicated, analgesics, and nonsteroidal anti-inflammatory drugs tailored to the patient's clinical profile. Repetitive or forceful dorsiflexion of the first MTP joint may exacerbate symptoms, whereas weight loss reduces forefoot loading during gait and may decrease both mechanical demand and local pain⁽¹⁹⁻²³⁾. Pharmacological therapy should be regarded as an adjunct to the other conservative measures, as robust evidence supporting medication alone for the treatment of hallux rigidus is lacking⁽¹⁸⁻²¹⁾.

Appropriate footwear is intended to minimize painful dorsiflexion of the first MTP joint, minimize dorsal impingement, decrease irritation of dorsal osteophytes, and redistribute plantar loading. Shoes with rigid soles and a high, wide toe box are generally preferred. Regarding sole design, rocker-soled shoes facilitate rollover from the hindfoot to the forefoot without requiring full dorsiflexion of the first MTP joint, whereas rigid-soled shoes act as a splint by limiting forefoot flexion, achieving a similar biomechanical objective^(19,20,22).

Orthotic treatment (e.g., rigid plates, Morton's extension, first-ray support orthoses, polypropylene devices, and custom-made orthoses) has yielded heterogeneous clinical outcomes. Retrospective studies and case series suggest symptomatic improvement in some patients, although controlled trials have substantially weakened this evidence^(17-19,23,24). Grady et al.⁽²³⁾ reported successful conservative treatment in 55% of 772 patients, most of whom (84%) were managed with orthotic devices. Similarly, Smith et al.⁽²⁴⁾ found that 75% of patients elected to continue nonoperative treatment despite radiographic progression in some cases, with the principal reason being that pain was not sufficiently severe to warrant surgery. In contrast, a multicenter trial of 88 participants comparing contoured foot orthoses with sham insoles found no significant differences in function or quality of life at 12 weeks. Likewise, an RCT including 100 participants

comparing rigid shoe inserts with sham devices found no differences in pain, function, or quality of life after 12 weeks. Collectively, these findings suggest that the effectiveness of orthotic treatment depends more on appropriate patient selection, comfort, footwear characteristics, and individual biomechanical factors than on a universally reproducible therapeutic effect^(17,19,20).

Physical therapy may serve as an adjunctive treatment for patients with early-stage disease, functional hallux rigidus, gait abnormalities, mechanical overload, posterior chain tightness, or first-ray dysfunction. Common interventions include mobilizing the first MTP joint and sesamoids, strengthening the flexor hallucis longus, gait retraining, stretching the gastrocnemius, soleus, and hamstring muscles, analgesic modalities, and patient education^(18,25). Shamus et al.⁽²⁵⁾ evaluated a rehabilitation protocol incorporating these interventions and reported short-term improvements in pain, muscle strength, and range of motion. However, because the study population consisted of young individuals without advanced disease, these findings cannot be readily extrapolated to patients with more severe hallux rigidus⁽²⁵⁾.

Intra-articular injections may provide temporary pain relief, particularly in patients with early or moderate-stage disease, clinically evident synovitis, acute symptom exacerbation, or a desire to postpone surgery. Corticosteroids and hyaluronic acid are the most commonly used injectable agents^(17,18,26-31). Solan et al.⁽²⁶⁾ investigated manipulation under anesthesia combined with intra-articular injection of a local anesthetic and corticosteroid and reported favorable outcomes, particularly in the early stages of the disease. In contrast, Munteanu et al.⁽²⁷⁾ found no clinically meaningful superiority of hyaluronic acid over saline in an RCT involving 151 patients. Similarly, Pons et al.⁽²⁸⁾ compared sodium hyaluronate with triamcinolone in an RCT and observed clinical improvement in both groups, but also a high rate of progression to surgical treatment within one year. More recently, the prospective, multicenter, uncontrolled REPAR study, published in 2022, evaluated image-guided injection of mannitol-modified cross-linked hyaluronic acid in 65 patients and showed a significant reduction in pain during walking at three months, with greater benefit in patients with mild to moderate radiographic disease^(30,31). However, robust evidence supporting sustained long-term benefit remains lacking. Collectively, these findings suggest that intra-articular injections may provide short-term symptomatic relief in selected patients, although larger, high-quality clinical trials are required before this intervention can be considered an established treatment for hallux rigidus.

Overall, nonoperative treatment should be offered to appropriately selected patients, particularly those with mild to moderate disease, because it is safe, minimally invasive, and may provide at least temporary symptom relief⁽¹⁷⁻²²⁾. A multimodal approach incorporating patient education, activity modification, analgesics and nonsteroidal anti-inflammatory drugs, rigid- or rocker-soled footwear, rigid orthoses or a Morton's extension, physical therapy, and selective intra-articular injections appears to be the most

rational conservative strategy. In advanced stages, however, treatment response is generally limited, and conservative management should be regarded primarily as a temporizing measure before definitive surgical intervention^(14,21,22,26).

Surgical treatment

Surgical treatment is indicated for patients who continue to experience pain and functional limitation despite at least six months of appropriate conservative management. Once surgery has been selected, the choice of procedure depends on multiple factors, including symptom severity, patient age, occupational and athletic demands, foot morphology, severity of the deformity, degree of joint mobility, and imaging findings, such as the metatarsal formula, extent of cartilage degeneration, presence of osteophytes, and subchondral cysts. The Coughlin and Shurnas⁽¹⁴⁾ classification incorporates symptoms, range of motion, and radiographic findings into a five-grade staging system and is useful for surgical decision-making. However, discrepancies among these components are common; for example, a patient may present with Grade 1 symptoms, Grade 2 radiographic changes, and Grade 3 limitation of motion. Nevertheless, it remains the most comprehensive and widely adopted classification for guiding surgical treatment⁽¹⁶⁾.

Patients with less severe disease (Grades 1 and 2) are candidates for joint-preserving procedures, including cheilectomy and decompression osteotomies, such as metatarsal shortening osteotomies and the Moberg osteotomy.

Coughlin and Shurnas⁽¹⁴⁾ reported long-term outcomes of cheilectomy in 93 feet (80 patients), with a mean follow-up of 9.6 years. Significant improvements were observed in dorsiflexion, pain, and American Orthopaedic Foot & Ankle Society (AOFAS) scores, and clinical outcomes were not associated with radiographic findings at follow-up. Pain relief and functional improvement were achieved in 68 feet (92%), and the authors concluded that cheilectomy provides the most predictable results in Grades 1 and 2 disease and in selected Grade 3 cases with more than 50% preservation of the articular cartilage.

In 2015, Nicolosi et al.⁽³²⁾ published a retrospective study evaluating the long-term outcomes of cheilectomy in 58 patients with hallux rigidus (mean age, 55 years) followed for more than seven years. The overall success rate was 87.9%, with 51 patients (87.9%) reporting no limitations in ADL, and only two patients (3.3%) requiring conversion to first MTP arthrodesis during follow-up.

Sidon et al.⁽³³⁾ subsequently reported a retrospective questionnaire-based study evaluating the long-term outcomes of cheilectomy in 165 patients (169 feet), with a mean follow-up of 6.6 years (range, 5-11 years). The questionnaire assessed post-surgery pain recurrence, current functional status, and patient satisfaction. Overall survivorship, defined as absence of pain at the latest follow-up, was 70.4% (119 feet), with no significant differences among preoperative radiographic grades. Most recurrences (75%) occurred within the first

two postoperative years. Overall, 69.3% of patients reported being satisfied or very satisfied with the procedure, and 75.1% stated that they would undergo the operation again under similar circumstances⁽³³⁾.

O'Malley et al.⁽³⁴⁾ demonstrated that combining the Moberg osteotomy with cheilectomy yields favorable clinical outcomes. The Moberg osteotomy shifts the center of contact plantarly on the proximal phalanx without altering either peak contact pressure or the overall contact area of the joint⁽³⁵⁾. Additional studies with shorter follow-up have also demonstrated favorable outcomes with minimally invasive cheilectomy^(36,37).

Montagna et al.⁽³⁸⁾ compared open cheilectomy combined with a Moberg osteotomy with the equivalent minimally invasive procedure and found no differences in functional outcomes. However, the open approach was associated with a higher rate of wound-related complications and greater postoperative opioid consumption.

A systematic review published in 2024 including 296 patients who underwent percutaneous cheilectomy with or without adjunctive arthroscopic shaver-assisted debridement showed an improvement in mean dorsiflexion from 32.4° preoperatively to 61.2° postoperatively, and all included studies reported improvements in clinical outcomes. The pooled complication rate was 6.1% (18 of 296 patients), with injury to the dorsomedial cutaneous nerve as the most common complication (2.0%)⁽³⁹⁾.

Another systematic review published in 2024 included 348 patients (370 feet) treated with percutaneous cheilectomy and a weighted mean follow-up of 37.9 months. The weighted mean AOFAS score improved from 68.9 preoperatively to 87.1 postoperatively. The overall complication rate was 8.4%, with persistent joint pain and stiffness representing the most common adverse events. Residual intra-articular bone fragments were identified in 100% of patients in one of the included studies. Overall, 32 failures (8.7%) and 33 secondary procedures (8.9%) were reported, with a weighted mean interval of 8.6 months between the index procedure and reoperation⁽⁴⁰⁾. An important advantage of cheilectomy is that, if the procedure fails, first MTP arthrodesis remains a reliable salvage option, with outcomes comparable to those achieved in patients undergoing primary arthrodesis without previous surgery⁽⁴¹⁾.

Another joint-preserving option for patients with early-stage hallux rigidus (Grades 1 and 2) is decompression metatarsal osteotomy. The rationale for these procedures is to achieve longitudinal decompression of the first MTP joint by shortening the first metatarsal while simultaneously translating the metatarsal head plantarly, thereby reducing tension in the surrounding soft tissues (including the plantar fascia, long flexor and extensor tendons, and joint capsule) and facilitating MTP dorsiflexion (Figures 2 and 3). These osteotomies were originally designed to correct either a relatively long first metatarsal (index plus or plus-minus) or metatarsus primus elevatus, based on the assumption that these anatomical characteristics increase loading across the

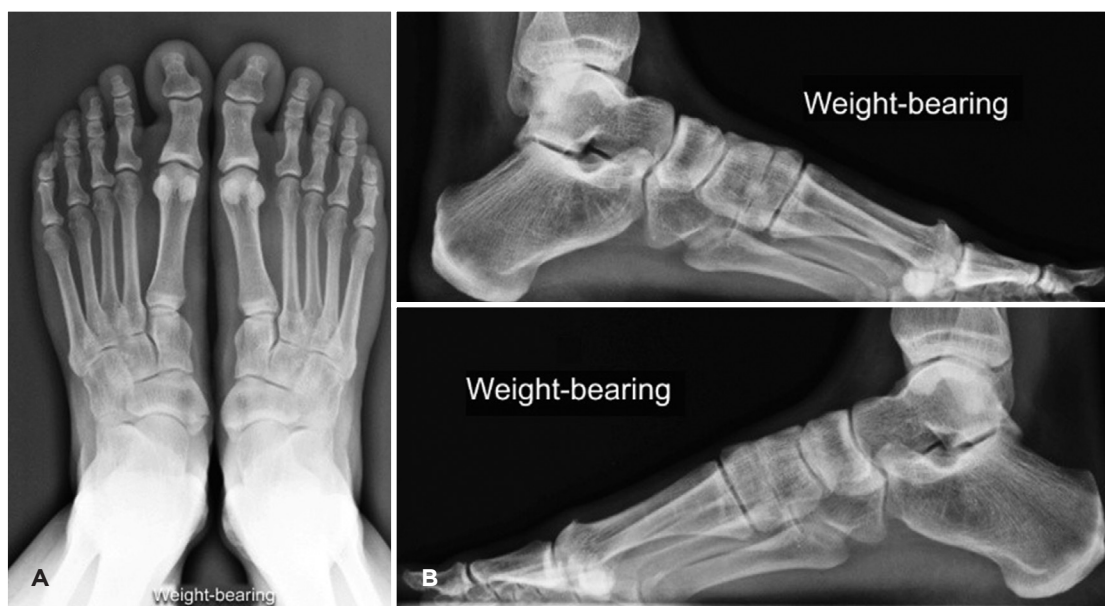


Figure 2. (A) Weight-bearing anteroposterior radiograph of both feet in a patient with Grade 2 hallux rigidus. (B) Weight-bearing lateral radiographs of the right and left feet, respectively.

Please note the relatively long first metatarsal (index plus) and the prominent dorsal osteophytes in both feet.



Figure 3. Postoperative radiographs following bilateral Youngswick osteotomy. (A) Weight-bearing anteroposterior view demonstrating shortening of the first metatarsal. (B) Weight-bearing lateral view demonstrating plantar displacement (depression) of the first metatarsal head achieved with the procedure.

first MTP joint. Although the role of these deformities in the pathogenesis of hallux rigidus remains controversial, the biomechanical rationale for these procedures is compelling.

The Youngswick-Austin osteotomy was developed to plantarflex a mildly elevated first metatarsal head and/or shorten a relatively long first metatarsal. Cöster et al.⁽⁴²⁾

compared the outcomes of 115 patients treated with a Youngswick decompression osteotomy and 181 patients treated with cheilectomy for moderate hallux rigidus. After one year, the mean improvement in Self-Reported Foot and Ankle Score was 12 points in the osteotomy group and 10 points in the cheilectomy group. Patients treated with osteotomy also reported greater satisfaction than those undergoing cheilectomy (84% vs. 70%)⁽⁴²⁾.

Slullitel et al.⁽⁴³⁾ retrospectively evaluated 61 patients with Grade 1 or 2 hallux rigidus who underwent a Youngswick osteotomy, with a mean follow-up of 54 months. Functional improvement, as measured by the Foot and Ankle Outcome Score (FAOS), was observed in all patients. Although radiographic progression occurred in 49% of cases, none required conversion to arthrodesis⁽⁴³⁾.

The modified Youngswick osteotomy is another effective joint-preserving procedure for physically active adults with moderate hallux rigidus, providing excellent pain relief, functional improvement, increased range of motion, and high rates of return to sports. Ceccarini et al.⁽⁴⁴⁾ retrospectively evaluated 52 physically active patients younger than 60 years with Grade 2 hallux rigidus who underwent a modified Youngswick osteotomy and were followed for at least 24 months. A total of 49 patients (94.2%) returned to sports participation. Significant improvements were observed in pain (Visual Analog Scale [VAS]), functional outcomes (European Foot and Ankle Society General and Sports-Specific scores), and first MTP dorsiflexion, which increased from a mean of 24.5° preoperatively to 52.5° postoperatively after a mean follow-up of 79 months. Two patients developed transfer metatarsalgia, and one required reoperation because of implant intolerance⁽⁴⁴⁾.

Viladot et al.⁽⁴⁵⁾ compared the Youngswick osteotomy with a distal oblique osteotomy (first-ray Weil osteotomy) for the treatment of moderate hallux rigidus. A total of 46 patients (50 feet) were included with a mean follow-up of 42 months. Both techniques produced significant improvements in range of motion and AOFAS scores, with no evidence that either procedure was superior⁽⁴⁵⁾.

Gerbert et al.⁽⁴⁶⁾ demonstrated, through a mathematical model, that the angle of the plantar limb of the osteotomy relative to the plantar surface determines the degree of plantar translation of the metatarsal head. In practical terms, a more horizontal plantar limb produces greater shortening of a relatively long first metatarsal, whereas a more vertical plantar limb results in greater plantar displacement of the metatarsal head, making it more suitable for correcting metatarsus primus elevatus⁽⁴⁶⁾.

Minimally invasive decompression osteotomy of the first ray has also been described for the treatment of early-stage hallux rigidus. However, cadaveric studies have highlighted the proximity of the burr portals to the extensor tendons and the dorsomedial cutaneous nerve of the hallux, emphasizing the potential risk of iatrogenic injury associated with this technique⁽⁴⁷⁾.

More advanced stages of hallux rigidus (Grades 3 and 4) are generally treated with non-joint-preserving procedures, including arthrodesis and arthroplasty. When successful, first MTP arthrodesis eliminates the arthritic joint, improves hallux weight-bearing by functionally “lengthening” the first ray, and, as an added benefit, alleviates concomitant transfer metatarsalgia when present. Although the procedure carries a risk of complications, particularly nonunion and malunion, anatomically contoured implants and strict adherence to surgical principles have substantially reduced these risks⁽⁴⁸⁻⁵⁰⁾.

One limitation of arthrodesis is the permanent loss of first MTP joint motion, which may affect return to certain athletic activities and the ability to wear high-heeled shoes. A recent systematic review of 153 patients (mean age, 58.6 years; mean follow-up, 18.9 months) demonstrated that return to sports following first MTP arthrodesis is highly variable and depends largely on both the patient and the specific sport. High rates of return to athletic activity were reported across several sports, with most patients describing postoperative athletic performance as equivalent to or better than their preoperative level. Approximately 10%-28% of patients reported improved athletic performance after surgery, 67.2%-87.5% reported no change, and only 1.8%-8.5% experienced greater difficulty participating in sports following hallux arthrodesis⁽⁵¹⁾.

Maor et al.⁽⁵²⁾ evaluated return to sports after first MTP arthrodesis in 16 elite athletes with a mean age of 27 years (range, 19-32 years) and a mean follow-up of 81 months (range, 60-121 months). A total of 12 athletes (75%) returned to their pre-injury level of competition within one year of surgery. Among the four athletes who did not, two soccer players were relegated to lower divisions, one Association of Tennis Professionals tennis player never regained his previous ranking, and one badminton player could not return to his pre-injury competitive level. Mean VAS pain scores improved significantly from 5.6 preoperatively to 0.4 at final follow-up ($p < 0.001$). Likewise, all FAOS subscales improved significantly, and every athlete reported being either satisfied or very satisfied with the surgical outcome. These findings indicate that most elite athletes can successfully return to high-level competition following first MTP arthrodesis and that even those who fail to regain their previous competitive level experience substantial improvements in pain and functional outcomes⁽⁵²⁾.

Among female patients, another common concern is the ability to wear high-heeled shoes after arthrodesis. A retrospective study evaluated 50 women who underwent isolated first MTP arthrodesis using a structured telephone interview that assessed the ability to wear high-heeled shoes before and after surgery, including heel height and duration of wear. The study included 50 patients (62 feet) with a mean age of 63 years (range, 43-78 years) at surgery and a mean follow-up of eight years (range, 5-16 years). Of the 42 patients who wore high heels preoperatively, 26 (62%) continued to do so after surgery, and 88% of these were able to wear heels of the same height as before the procedure. Overall, the results

suggest that many women can continue wearing high-heeled footwear after hallux arthrodesis with minimal or no symptoms in adjacent joints⁽⁵³⁾.

Scheurer et al.⁽⁵⁴⁾ evaluated 61 first MTP arthrodeses and compared outcomes among 28 patients younger than 50 years and 33 patients older than 60 years. After a mean follow-up of 14 years, no significant differences in functional outcomes were observed between the two groups. Pain relief, however, was more pronounced in younger patients, demonstrating that first MTP arthrodesis is an excellent treatment option across age groups⁽⁵⁴⁾.

From a technical standpoint, fixation with a dorsal plate combined with an interfragmentary compression screw provides greater stability than other fixation methods for first MTP arthrodesis^(48-50,55,56). In a retrospective study of 417 patients (450 feet), nonunion occurred in 25 cases (5.5%) and was associated with bilateral surgery and peripheral neuropathy⁽⁵⁷⁾. Other factors associated with nonunion include obesity, concomitant hallux valgus deformity, and use of convex-concave reamers for joint preparation⁽⁵⁸⁾.

Pinter et al.⁽⁵⁹⁾ compared outcomes in 36 patients who underwent first MTP arthrodesis using a dorsal plate combined with a compression screw and 63 patients treated with dorsal plate fixation alone. Union rates were 89% and 84%, respectively. More importantly, the mean change in dorsiflexion angle between the immediate postoperative period and final follow-up was substantially smaller in the combined fixation group (0.57° vs. 6.73°), indicating significantly greater sagittal-plane stability and a lower risk of malunion with combined fixation⁽⁵⁹⁾. Biomechanical studies have similarly shown that both dorsal plate fixation combined with an interfragmentary screw and crossed interfragmentary screws alone provide sufficient construct stiffness and strength to permit protected weight-bearing, provided forefoot loading is avoided during the early postoperative period^(55,59).

Osteoarthritis in adjacent joints is a recognized concern following arthrodesis of any joint. However, after first MTP arthrodesis, this phenomenon appears to have limited clinical relevance. In a study of 77 patients with a mean follow-up of nine years, radiographic osteoarthritic changes developed in adjacent joints, predominantly the interphalangeal joint, in 66 patients. Nonetheless, 90.9% of patients were satisfied with the surgical outcome and reported minimal or no symptoms related to the adjacent joints⁽⁶⁰⁾.

As an alternative to arthrodesis for advanced hallux rigidus, arthroplasty may be performed with or without an implant. Interpositional arthroplasty is a joint-preserving resection arthroplasty that does not require prosthetic implantation and consists of cheilectomy, a Keller osteotomy, and interposition of autologous or allogeneic tissue.

In 1997, Hamilton et al.⁽⁶¹⁾ described an interpositional arthroplasty technique using the dorsal capsule and extensor hallucis brevis tendon in 37 feet from 30 patients. Pain and function improved significantly without transfer metatarsalgia. All patients achieved at least grade 4/5

plantarflexion strength and a mean dorsiflexion of 50° ⁽⁶¹⁾.

Sanhudo et al.⁽⁶²⁾ reported outcomes for 25 feet with advanced hallux rigidus (Grades 3 and 4) treated with a modified dorsal capsular interpositional arthroplasty and followed for a minimum of 15 months (Figure 4). The mean AOFAS score at final follow-up was 93.6 points; 75% of patients were completely satisfied; no patient demonstrated less than 30° of first MTP joint motion at final follow-up; and only one patient developed mild transfer metatarsalgia⁽⁶²⁾. In the author's experience, this procedure is particularly well suited for patients with an index plus or plus-minus metatarsal formula, lower functional demands, and female patients who wish to preserve first MTP joint motion for wearing high-heeled shoes.

In 2017, Aynardi et al.⁽⁶³⁾ published a retrospective review of patients who underwent interpositional arthroplasty between 2001 and 2014. Procedure survivorship, functional outcomes,

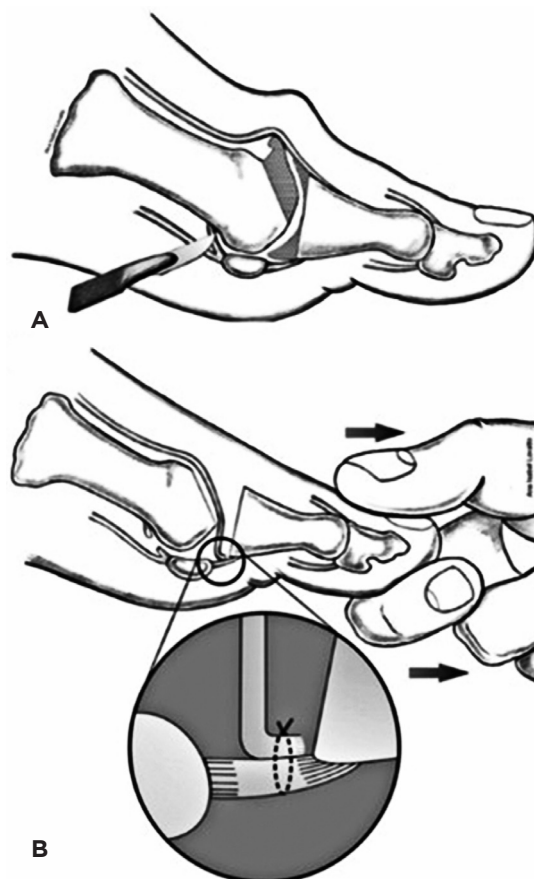


Figure 4. Schematic representation of the modified interpositional arthroplasty. (A) Release of the contracted proximal metatarsosesamoid ligament, generous cheilectomy, and limited resection of the base of the proximal phalanx to minimize shortening of the first ray. (B) Interposition of the dorsal capsule with fixation to the plantar plate.

and patient satisfaction were assessed by telephone interview. The study included 133 patients with a mean follow-up of 62.2 months (range, 24.3–151.2 months). The overall failure rate was 3.8% (5 of 133 patients). Patient-reported outcomes were rated as excellent in 65.4% of cases, good in 24.1%, and fair or poor in only 10.5%. Transfer metatarsalgia was reported by 23 (17.3%) patients at final follow-up⁽⁶³⁾.

Vulcano et al.⁽⁶⁴⁾ subsequently published a retrospective study of 42 patients who underwent interpositional arthroplasty between 1998 and 2011. After a mean follow-up of 11.3 years (range, 4–16 years), mean VAS pain scores improved from 7.9 preoperatively to 1.8 postoperatively, and significant improvements were observed in both Foot Function Index and Short Form-12 scores. Overall satisfaction was high, with 92.9% of patients reporting that they would choose the same procedure again under similar circumstances. Four patients (9.5%) required conversion to first MTP arthrodesis at a mean of 6.1 years after the index procedure⁽⁶⁴⁾.

Mroczek et al.⁽⁶⁵⁾ subsequently described a modification of interpositional arthroplasty consisting of an oblique osteotomy of the proximal phalanx while preserving the insertion of the flexor hallucis brevis. This modification increases joint stability and minimizes the risk of postoperative hallux extension deformity (cock-up deformity)^(65–67).

More recently, Johnson et al.⁽⁶⁷⁾ compared the long-term outcomes of 15 patients treated with modified oblique Keller capsular interposition arthroplasty (MOKCIA), with a mean follow-up of 15 years, and 20 patients treated with first MTP arthrodesis, with a mean follow-up of 13 years. Patients treated with MOKCIA reported higher satisfaction scores and lower pain scores at final follow-up, suggesting this procedure is a durable, motion-preserving alternative to arthrodesis⁽⁶⁷⁾. Similarly, Thome et al.⁽⁶⁸⁾ compared 58 feet treated with MOKCIA and 112 feet treated with arthrodesis after a mean follow-up of 13 years. Compared with their preoperative status, patients in the arthroplasty group reported less difficulty participating in sports than those treated with arthrodesis. Patient-Reported Outcomes Measurement Information System (PROMIS), VAS, and FAAM-Sports subscale scores were similar between groups, whereas satisfaction with postoperative activity level was higher in the arthroplasty group than in the arthrodesis group (100% vs. 87%)⁽⁶⁸⁾.

In 2022, Butler et al.⁽⁶⁹⁾ published a systematic review including 498 patients from 16 studies (one Level III and 15 Level IV studies). The mean AOFAS Hallux Metatarsophalangeal-Interphalangeal score improved from 51.6 preoperatively to 86.0 postoperatively after a weighted mean follow-up of 58 months. The weighted mean total range of motion increased from 39.3° preoperatively to 61.5° postoperatively. The overall complication rate was 21.5%, with transfer metatarsalgia as the most frequently reported complication⁽⁶⁹⁾.

In 2016, an industry-sponsored RCT comparing first MTP arthrodesis with hemiarthroplasty using a polyvinyl alcohol hydrogel implant reported equivalent pain relief and functional outcomes after two years of follow-up⁽⁷⁰⁾; however, subsequent studies have not reproduced these initial findings.

El Masry et al.⁽⁷¹⁾ compared 82 patients treated with polyvinyl alcohol hydrogel hemiarthroplasty and 101 patients treated with first MTP arthrodesis. Patients in the arthrodesis group experienced greater pain relief at both one and two years, and functional scores at two years were also significantly superior to those of the hemiarthroplasty group⁽⁷¹⁾. Likewise, Chrea et al.⁽⁷²⁾ compared 73 patients treated with cheilectomy plus Moberg osteotomy with 60 patients treated with the same procedure combined with a hydrogel implant. Pain relief was equivalent after one to two years of follow-up, suggesting that omitting the implant reduces both cost and implant-related risks without compromising clinical outcomes⁽⁷²⁾.

Another study involving 21 patients treated with hydrogel hemiarthroplasty demonstrated that 18.2% required reoperation and that 55% continued to experience pain and limited joint motion after a minimum follow-up of two years⁽⁷³⁾. Similarly, Sanii et al.⁽⁷⁴⁾ evaluated 99 patients with at least 12 months of follow-up and found hydrogel arthroplasty to be inferior to both arthrodesis and implant-free interpositional arthroplasty with respect to pain relief and functional outcomes.

In contrast, Glazebrook et al.⁽⁷⁵⁾ demonstrated satisfactory medium- and long-term implant survivorship following hydrogel arthroplasty. However, conversion to arthrodesis after implant failure resulted in higher nonunion rates and inferior functional outcomes compared with primary arthrodesis⁽⁷⁵⁾. Furthermore, a systematic review by Butler et al.⁽⁷⁶⁾ including 1,367 feet treated with hydrogel arthroplasty reported an overall complication rate of 27.9%, a failure rate of 14.8%, and a reoperation rate of 9.5% after a mean follow-up of only 24 months.

A systematic review published in 2024 compared arthrodesis with metallic, hydrogel, and double-stem silicone arthroplasties across 26 studies involving 1,348 feet⁽⁷⁷⁾. In the arthrodesis group, the AOFAS Hallux Metatarsophalangeal-Interphalangeal score improved from 36–45 preoperatively to 79–89 postoperatively, with an overall union rate of 98.6%. Implant-related hardware discomfort was the most common complication. Among metallic implants, the ROTOGlide® system achieved a mean AOFAS score of 95 with low complication rates. However, the ToeFit Plus™ and BioMed-Merck systems demonstrated revision rates of 37% and 15%, respectively, primarily because of aseptic loosening in studies with longer follow-up. Patients treated with hydrogel implants experienced marked improvements in FAAM-ADL and FAAM-Sports scores, increasing from 59.4 to 90.4 and from 60.9 to 89.7, respectively. Nevertheless, implant removal and conversion to arthrodesis were required in 20.5% of cases. Finally, among patients treated with double-stem silicone arthroplasty, the study with the longest follow-up reported improvement in the Manchester-Oxford Foot Questionnaire score from 78.1 to 11.0 and a mean postoperative range of motion of 22.3°, although periprosthetic osteolysis was observed in 10% of cases⁽⁷⁷⁾.

Overall, implant arthroplasty has produced inconsistent results in the literature. Given its high cost and the risks associated with prosthetic implantation, it should not be considered the first-line surgical treatment for hallux rigidus.

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Special Article

Anatomical structures at risk in third- and fourth-generation minimally invasive hallux valgus surgery: A comprehensive review

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Abstract

A critical limitation common to all minimally invasive surgery (MIS) approaches is the lack of direct visualization during osteotomy execution, which exposes arteries, nerves, and tendon insertions to iatrogenic injury within a confined anatomical space. This review synthesizes applied anatomical knowledge relevant to third- and fourth-generation MIS for hallux valgus (HV), incorporating findings from cadaveric dissection and micro-computed tomography (CT) vascular mapping to characterize the tendinous, neural, vascular, and sesamoid architecture of the first metatarsal head complex and to define quantitative safety zones for intraoperative reference. Micro-CT perfusion studies have established that the apex of the Chevron osteotomy should be positioned at a minimum distance of 25.6 mm (dorsal arm) and 23.9 mm (plantar arm) from the most distal point of the first metatarsal articular surface, with the excursion of the Shannon burr limited to 3.9 mm and 4.0 mm beyond the exit point on the lateral cortex. The Metaphyseal Extra-Articular Transverse and Akin Osteotomy (META) technique introduces a geometrically distinct risk profile by simultaneously addressing the dorsal and plantar metatarsal arteries in a single transverse plane; for this technique, a unified safety distance of approximately 26 mm is proposed for the osteotomy, pending specific anatomical application and micro-CT validation. Neurological risk for both osteotomy generations centers on the dorsomedial nerve of the first toe. Biomechanical and radiographic equivalence between third- and fourth-generation constructs indicates that the choice of technique should be guided by surgical training rather than perceived mechanical superiority, and that safe execution depends on mastering the anatomical boundaries described in this review.

Level of Evidence V; Expert Opinion, Basic Science Study.

Keywords: Hallux valgus; Minimally invasive surgical procedures; Osteotomy; Micro-CT scan; Nerve injury.

Introduction

Hallux valgus (HV) represents one of the most prevalent forefoot deformities, affecting an estimated 19% of the general population worldwide, with a marked female predominance and increasing prevalence with age^(1,2). The condition is a complex three-dimensional (3D) deformity characterized by a lateral deviation of the hallux at the first metatarsophalangeal joint (MTPJ), concurrent with medial deviation of the first

metatarsal, and is associated with significant impairment of health-related quality of life, affecting gait, balance, footwear tolerance, and psychosocial well-being⁽¹⁻⁴⁾.

Surgical correction is the standard of care for symptomatic HV that has failed conservative management, with over 150 operative techniques described in the literature⁽⁵⁾. Among these, minimally invasive surgery (MIS) has gained substantial traction over the past two decades. Compared with tradi-

Study performed at the Department of Orthopedics and Rehabilitation, University of Iowa, Iowa City, IA, USA and Human Anatomy and Embryology Unit, Experimental Pathology and Therapeutics Department, University of Barcelona, Spain.

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onal open procedures, MIS techniques offer smaller incisions, reduced soft tissue dissection, lower postoperative pain, earlier weight-bearing, and faster return to activity^(6,7).

Minimally invasive surgery for HV has evolved through four successive generations. First-generation percutaneous techniques (e.g., Reverdin-Isham osteotomy) used intra-articular osteotomies without internal fixation, restricted to mild-to-moderate deformities. Second-generation techniques (e.g., Bösch technique) employed extra-articular transverse osteotomies stabilized with Kirschner wires, offering improved bone union but limited rotational control⁽⁸⁾. Third-generation minimally invasive techniques for HV correction, such as the Minimally Invasive Chevron-Akin (MICA) procedure described by Vernois and Redfern, combined a percutaneous, chevron-shaped distal metatarsal osteotomy with rigid fixation using two screws, providing sufficient intrinsic stability to allow early weight-bearing and substantial lateral translation of the metatarsal head, even in cases of severe deformity^(9,10). Variations of this concept, including the Percutaneous Intra-articular Chevron Osteotomy (PeICO) described by Del Vecchio et al.⁽¹¹⁾, replicate the geometry and angulation of the classic open Chevron osteotomy while requiring only a single screw for fixation. Fourth-generation techniques, as described by Lewis et al.⁽¹²⁾ in the Metaphyseal Extra-articular Transverse and Akin Osteotomy (META), preserve the principle of rigid fixation with two fully threaded screws – at least one of which must be bicortical – but replace the Chevron geometry with a transverse, extra-articular osteotomy. This configuration is intentionally less stable at the osteotomy site, which permits an active three-dimensional reduction maneuver capable of correcting not only the intermetatarsal and hallux valgus angles but also the rotational (pronation) component of the deformity, a correction that Chevron-based designs are less able to achieve due to their inherent geometric stability⁽⁹⁻¹³⁾.

A critical limitation inherent to all MIS approaches is the absence of direct visualization during osteotomy execution⁽¹³⁻¹⁵⁾. The Shannon burr operates within a confined anatomical space populated by major arterial pedicles,

cutaneous nerves, and tendinous insertions – all of which are at risk of iatrogenic injury⁽¹⁴⁾. Paradoxically, the literature on MIS outcomes rarely characterizes these complications in detail, and quantitative data on safe distances from at-risk structures remain scarce.

This review synthesizes applied anatomical knowledge relevant to the practice of third- and fourth-generation MIS HV surgery, incorporating cadaveric dissection findings and micro-computed tomography (CT) vascular mapping. The objective is to provide the operating surgeon with a structured, evidence-based framework for understanding the anatomical risk zones and safe operating corridors when performing MIS third- and fourth-generation distal metatarsal osteotomies to treat HV deformities.

Applied anatomy of the first metatarsal head complex

The first metatarsal head complex encompasses a constellation of tendinous, ligamentous, neural, and vascular structures that converge upon the first metatarsophalangeal joint (MTPJ). Intimate knowledge of their spatial relationships is indispensable for safe MIS execution⁽¹⁶⁾. The relevant structures may be organized into four anatomical domains: tendons, nerves, blood supply, and the sesamoid complex⁽¹⁶⁾.

Tendons of the first metatarsal head complex

The extensor hallucis longus (EHL)

The EHL muscle's primary function is hallux extension and ankle dorsiflexion. Its tendon insertion on the distal phalanx of the hallux also contributes to weak foot inversion. Originating on the fibula and inserting on the distal phalanx of the hallux, EHL contraction results in elevation of the foot and hallux toward the tibia. This action is essential for gait, enabling foot clearance during the swing phase. Injury to the deep peroneal nerve, which innervates the EHL, can lead to foot drop, characterized by weakened dorsiflexion and a characteristic high-stepping gait pattern (Figure 1A)⁽¹⁶⁻¹⁹⁾.

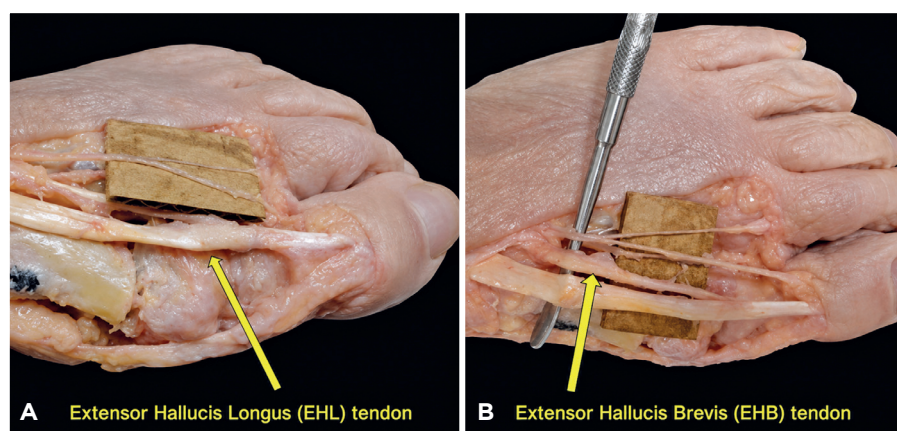


Figure 1. First metatarsal head dorsal aspect: (A) the extensor hallucis longus (EHL) and (B) the extensor hallucis brevis (EHB) tendons.

Source: Carvalho (2025)⁽¹⁶⁾

The extensor hallucis brevis (EHB)

The EHB is regarded as a distinct medial slip of extensor digitorum brevis. This muscle thus originates from the superolateral surface of the distal calcaneus, from the interosseous talocalcaneal ligament, and from the deep aspect of the base of the inferior extensor retinaculum. Its tendon inserts onto the dorsal surface of the base of the proximal hallux phalanx (Figure 1B). It is innervated by the deep fibular (peroneal) nerve^(16,20).

The flexor hallucis longus (FHL)

The FHL muscle originates from the posterior aspect of the fibula. Its tendon courses through the tarsal tunnel, passing inferior to the medial malleolus of the tibia, and inserts onto the distal phalanx of the hallux (Figure 2)^(16,21,22). The FHL's primary action is flexion of the hallux. It also contributes to plantar-medial force distribution within the forefoot, providing support to the medial longitudinal arch^(16,23).

The flexor hallucis brevis (FHB)

The FHB, an intrinsic muscle of the foot, originates along the plantar aspect of the cuboid and cuneiform bones^(16,24). The FHB divides distally into two portions that are inserted on the medial and lateral aspects of the base of the proximal phalanx of the hallux. The medial head of the FHB, the larger of the two, inserts medially on the plantar plate and shares a common tendon with the abductor hallucis muscle prior to its insertion on the base of the proximal phalanx^(16,25). An accurate understanding of this insertion is critical in surgical procedures involving the first MTPJ, particularly those addressing HV^(16,26).



Figure 2. First metatarsal head plantar aspect: The flexor hallucis longus (FHL) tendon.

Source: Carvalho (2025)⁽¹⁶⁾

The abductor hallucis (AH)

The AH is the most superficial muscle in the medial compartment of the first layer of the plantar aspect of the foot, has a proximal attachment primarily to the flexor retinaculum and posterior calcaneal tuberosity, with some fibers also attaching to the intermuscular septum separating it from the FHB^(16,27,28). Distally, its tendon inserts onto the base of the proximal phalanx of the hallux (Figure 3A). Innervated by a branch of the medial plantar nerve and supplied by a branch of the medial plantar artery, the AH contributes to maintaining the medial longitudinal arch of the foot. Muscle contraction results in abduction of the hallux^(16,20,27,28).

The adductor hallucis

The adductor hallucis muscle, composed of the oblique and transverse heads, is responsible for the adduction of the great toe⁽²⁹⁾. The transverse head arises from the ligaments associated with the MTPJ of the three lateral toes. In contrast, the oblique head arises from the bases of metatarsals II through IV and the sheath covering the peroneus longus tendon (Figure 3B)⁽²⁹⁾. According to Sarrafian's⁽³⁰⁾ description of the insertion of the adductor hallucis, the distal segment of the oblique head consists of three components, each attaching to the fibular sesamoid, with the lateral component extending to the plantar lateral aspect of the base of the proximal phalanx^(30,31). Its action is adduction of the great toe at the MTPJ. The adductor hallucis receives its arterial supply from the lateral plantar artery and is innervated by the lateral plantar nerve, a branch of the tibial nerve^(29,32). Knowledge of this anatomical configuration highlights the potential risk of injury during surgical correction of the HV when performing a release along the base of the proximal phalanx⁽¹⁶⁾.

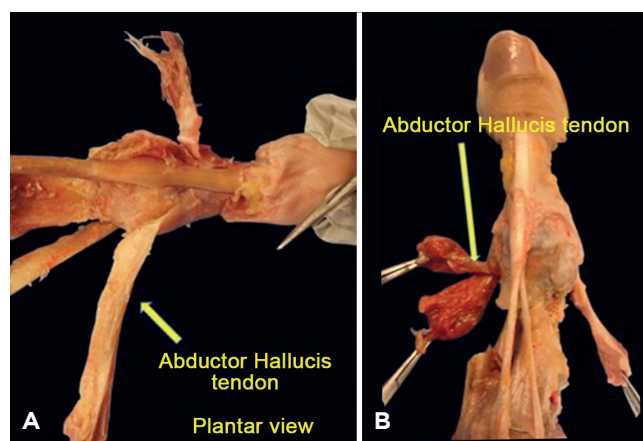


Figure 3. First metatarsal head medial aspect: (A) the abductor hallucis tendon. First metatarsal head lateral aspect: (B) the adductor hallucis tendon.

Source: Carvalho (2025)⁽¹⁶⁾

Nerves of the first metatarsal head complex

Iatrogenic injury to subcutaneous nerves on the dorsum of the foot is an established risk factor during surgical procedures, including HV correction, resulting in postoperative pain, sensation loss, and painful neuroma^(16,33-36).

The deep peroneal nerve (DPN) and the superficial peroneal nerve (SPN) arise from the common peroneal nerve that supplies the skin on the distal anterior aspect of the leg and the dorsal aspect of the foot^(16,31,37). The DPN innervates the skin at the interdigital space between the first and second toes, and the SPN innervates the remaining part of the dorsum of the foot^(16,35).

The dorsomedial nerve of the first toe and its medial branch emerge from SPN, and the dorsolateral nerve of the first toe and the dorsomedial nerve of the second toe emerge from DPN (Figure 4)^(16,33,34).

Blood supply of the first metatarsal head complex

The extrinsic vascular supply to the first metatarsal originates from the first dorsal metatarsal artery (FDMA), the lateral dorsal branch of the FDMA, and the first plantar metatarsal artery (FPMA). These arteries give rise to localized branches within the first metatarsal, which further subdivide into smaller arteries surrounding the periosteum and joint capsule^(14,16,30,31,38).

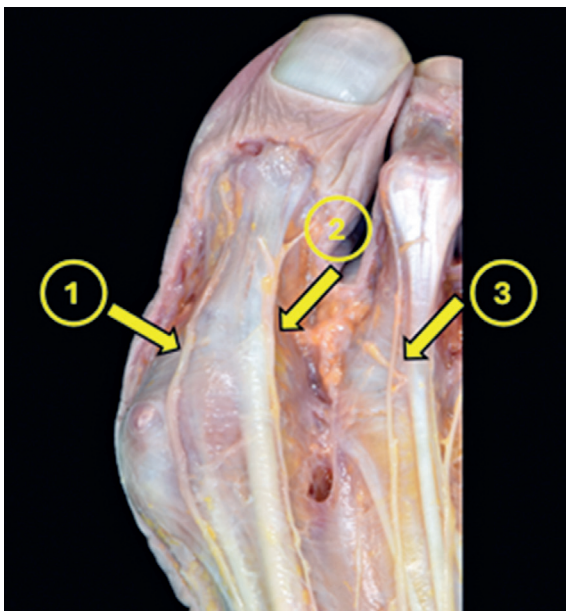


Figure 4. Dorsal view of a foot showing the typical distribution of dorsomedial and dorsolateral nerves: 1. Dorsomedial nerve of the first toe. 2. Dorsolateral nerve of the first toe. 3. Dorsomedial nerve of the second toe (yellow arrows).

A cadaveric study by Jones et al.⁽³⁹⁾ visualized an extensive arterial network forming a plexus around the first metatarsal head. This plexus, often difficult to visualize during standard surgical dissection, migrates dorsally from the FDMA and its dorsal branch and plantarly from the FPMA^(14,16,39). These arteries converge to form a plexus at the metatarsal neck, proximal to the capsular insertion (Figure 5)^(14,16,30,31,38-40).

Iatrogenic vascular damage to the metatarsal head, including injury to the intramedullary and metaphyseal blood supply, can occur during surgical procedures, potentially due to excessive penetration of the Shannon burr during osteotomy^(16,39,40).

The sesamoid complex

The hallux sesamoid complex, located plantar to the first MTPJ, plays a critical biomechanical role, transmitting up to 50% of body weight during normal activities and exceeding 300% during push-off⁽⁴¹⁾. The greater tibial sesamoid resides on the medial head of the FHB, while the lesser fibular sesamoid is located on the lateral head^(41,42). Both sesamoids receive tendinous insertions from the adductor and abductor hallucis muscles. The medial and lateral sesamoid ligaments, originating from the respective aspects of the metatarsal head, insert onto the corresponding aspects of the tibial and fibular sesamoids, forming part of the plantar plate of the first MTPJ^(43,44). The fibular sesamoid connects to the second metatarsal neck via the deep intermetatarsal ligament⁽⁴³⁾. A thick intersesamoid ligament unites the tibial and fibular sesamoids, constituting the central component of the plantar plate (Figure 6)^(41,45). Accurate assessment of sesamoid subluxation in HV has historically been challenging, but its recognition is crucial to guide HV treatment^(16,46). Inadequate assessment and correction of sesamoid subluxation may increase the risk of postoperative recurrence of HV⁽¹⁶⁾.

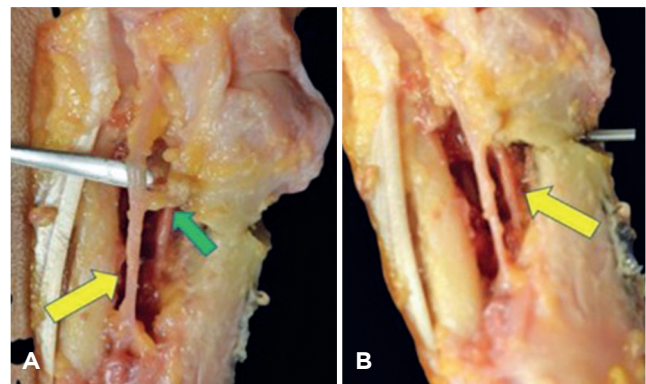


Figure 5. First metatarsal head blood supply (Macroscopically): (A) first dorsal metatarsal artery (FDMA) (yellow arrow), lateral dorsal branch of FDMA (green arrow), (B) first plantar metatarsal artery (yellow arrow).

Micro-CT assessment of the first metatarsal head vascularity

To precisely characterize the vascular architecture of the first metatarsal head, cadaveric specimens were injected with a low-viscosity radiopaque polymer and subsequently analyzed by micro-CT^(14,16). This technique provided three-dimensional visualization of the arterial network at a resolution beyond the capability of conventional imaging, mapping the intramedullary, metaphyseal, and periosteal vessels relative to the osteotomy geometry^(14,16).

Micro-CT imaging confirmed that the FDMA, its lateral dorsal branch, and the FPMA form an interconnecting plexus at the metatarsal neck that migrates dorsally from above and plantarly from below, converging proximal to the capsular insertion. This plexus provides the primary intramedullary blood supply to the metatarsal head via nutrient channels that penetrate the cortex in the dorsolateral and plantar-lateral quadrants (Figure 7)^(14,16).

Third- and fourth-generation MIS techniques: Anatomical considerations

Third-generation: MICA and PeICO techniques

The MICA technique, as described by Vernois and Redfern^(9,10), employs a distal extra-articular Chevron-shaped osteotomy using a 20 × 2-mm Shannon burr introduced through a medial stab incision at the metatarsal neck. The osteotomy is oriented with the apex medially, creating a dorsal arm directed superiorly and a plantar arm directed inferiorly, both converging to exit the lateral cortex.

Carvalho et al.^(14,16), in a cadaveric and micro-CT study of the MICA technique, provided detailed anatomical mapping of the vascular structures at risk during the Chevron-type osteotomy. From an anatomical standpoint, this study demonstrates that the dorsal arm of the osteotomy passes in close proximity to the FDMA and its lateral dorsal branch, which course dorsolaterally through the first web space and converge at



Figure 6. First metatarsal head distal aspect: (A and B) the sesamoid complex.

Source: Carvalho (2025)⁽¹⁶⁾

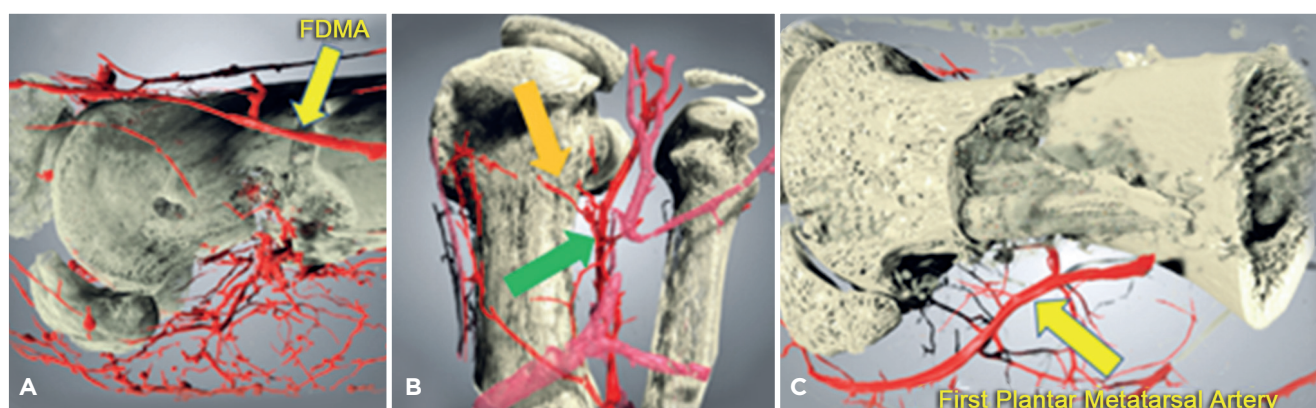


Figure 7. First metatarsal head blood supply (Micro-CT images): Lateral view (A) first dorsal metatarsal artery (FDMA) (yellow arrow), (B) antero-posterior view: Lateral dorsal branch of FDMA (orange arrow) and FDMA (green arrow), (C) oblique view: First plantar metatarsal artery (yellow arrow).

Source: Carvalho (2025)⁽¹⁶⁾

a bifurcation located a median of 25.6 mm proximal to the most distal point of the first metatarsal head. The plantar arm, in turn, runs trajectorially adjacent to the FPMA and the lateral head of the FHB, with the FPMA trifurcating into its sesamoid and metatarsal head branches at a median distance of 23.9 mm from the same distal reference point. The final phase of both arms – the moment the Shannon burr exits the lateral cortex – represents the point of maximum vascular risk, since any further advancement beyond this threshold engages the soft tissue envelope directly; micro-CT analysis established this safe penetration margin at 3.9 mm dorsolaterally (protecting the FDMA) and 4.0 mm plantar-laterally (protecting the FPMA), beyond which the arterial plexus becomes vulnerable to iatrogenic injury (Figure 8).

Del Vecchio et al.⁽¹¹⁾, in a cadaveric study on the PeICO technique for HV correction, demonstrated that the primary portal (P1) lies in close anatomical proximity to critical neurovascular and tendinous structures. The mean distance between P1 and the dorsomedial digital nerve (DMDN) was only 7.3 mm (range 1.6-10.4 mm), while its distance from the lateral border of the EHL tendon averaged 17.6 mm. Notably, the osteosynthesis portal (P2), positioned approximately 15 mm proximal and 3 mm dorsal to P1, exhibited the narrowest safety margin of the entire procedure with respect to the DMDN, with a mean distance of only 4.1-4.2 mm – identifying this portal as the site of greatest neurological risk throughout the technique. Creation of the dorsal limb of the osteotomy, oriented perpendicular to the first metatarsal diaphysis

at an angle of 10 to 20 degrees from the apex, demands heightened surgical vigilance along this same trajectory, since advancement of the burr in this region brings the instrument into direct proximity with the dorsomedial neurovascular envelope, all without direct visualization of the underlying structures (Figure 9)⁽¹¹⁾.

Fourth-generation: Transverse osteotomy with rigid fixation

Fourth-generation MIS for HV, described by Lewis et al.⁽¹²⁾ under the acronym META, substitutes the Chevron geometry with a transverse metaphyseal cut, allowing multiplanar rotational correction. Fixation is achieved with two fully threaded screws, at least one bicortical.

The anatomical risk profile of the transverse osteotomy differs from the Chevron in that the burr traverses the full transverse diameter around the metatarsal neck in a single plane, rather than in a V-shaped trajectory^(12,13,14). This means that both the FDMA (above) and the FPMA (below) are approached simultaneously during the lateral cortex exit phase (Figure 10). The absence of a well-defined apex, in theory, reduces the directional predictability of the burr's cortical exit – particularly in hands not specifically trained in MIS technique and/or without the use of industry-specific jigs designed to guide burr orientation – potentially increasing the risk of exceeding safe soft tissue margins laterally if the technique is imprecise.

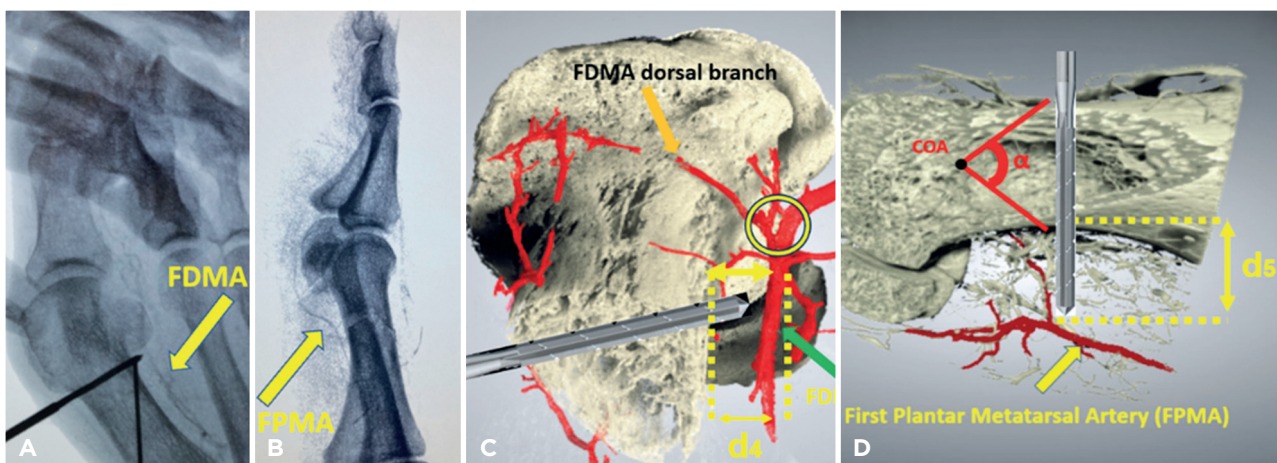


Figure 8. Vascular structures at risk during minimally invasive surgery Chevron-type osteotomy: Contrast-enhanced fluoroscopic images showing the first dorsal metatarsal artery (FDMA) (yellow arrow) (A) and first plantar metatarsal artery (FPMA) (yellow arrow) (B), and their relationship to Shannon Burr. Safe distance to advance with the Shannon Burr from the first metatarsal cortex (C) without injuring the FDMA (green arrow) (d4), and (D) to avoid injury to the FPMA (yellow arrow) (d5). (C) Distance, d4: distance between the lateral cortex exit point of the minimally invasive surgery Chevron-type osteotomy on the first metatarsal and the FDMA (dorsal plane); FDMA dorsal branch (orange arrow). (D) Distances, d5: distance between the lateral cortex exit point of the minimally invasive surgery Chevron-type osteotomy on the first metatarsal and the FPMA (plantar plane). COA: Chevron osteotomy apex (black circle); Alpha angle (α): Angle between the dorsal and the plantar arms of the minimally invasive surgery Chevron-type osteotomy.

Source: Carvalho (2025)⁽¹⁶⁾

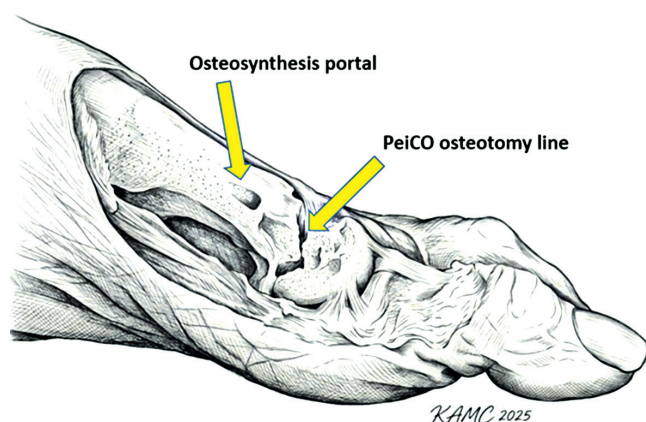


Figure 9. Schematic drawing depicting the percutaneous, intra-articular chevron osteotomy (PeiCO) technique, demonstrating the chevron osteotomy line at the head of the first metatarsal and the corresponding osteosynthesis portal (yellow arrows), used for insertion of the fixation material.

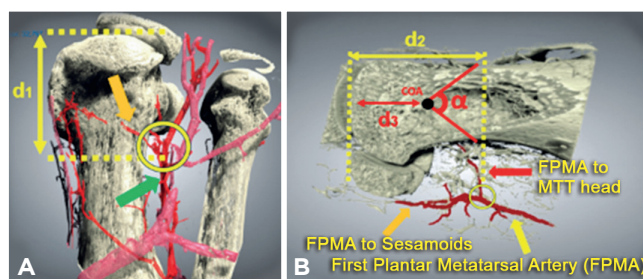


Figure 10. Safe position for performing minimally invasive surgery Chevron-type osteotomy (Micro-CT images). (A) Antero-posterior view: Anatomical reference landmarks, namely the bifurcation (inside of the yellow circle), between the first plantar metatarsal artery (FDMA) (green arrow) and the Lateral Dorsal Branch of the FDMA (orange arrow), along with the most distal portion of the first metatarsal head. (B) Lateral view: Anatomical reference landmarks, namely the trifurcation (inside of the yellow circle), between the FPMA (yellow arrow) and its branches to sesamoids (orange arrow) and the first metatarsal head (red arrow). (B) COA: Chevron osteotomy apex (black circle); Alpha angle (α): Angle between the dorsal and the plantar arms of the minimally invasive surgery Chevron-type osteotomy. (A) Distance, d1: between the most distal point of the first metatarsal head and the bifurcation of the FDMA and its lateral dorsal branch. (B) Distances, d2: between the most distal point of the first metatarsal head and the trifurcation between the FPMA and its branches to the sesamoids and the first metatarsal head; and d3: between the metatarsal neck's flare and the most distal point of the first metatarsal head.

Source: Carvalho (2025)⁽¹⁶⁾

Biomechanical studies have shown no significant difference in ultimate load or stiffness between third- and fourth-generation MIS constructs, and comparative radiographic outcome studies have found no significant difference in angular correction⁽⁴⁸⁾. The choice between geometries should therefore be guided principally by surgeon familiarity and comfort, rather than perceived biomechanical superiority^(12,13,48-50).

Quantitative safe zones for MIS third- and fourth-generation osteotomy

The determination of safe operating distances – measured by defined fluoroscopic landmarks – is the primary practical contribution of the cadaveric and micro-CT studies reviewed here^(14,16). These distances were established from a population of 20 cadaveric specimens with HV, all undergoing standardized MIS Chevron-type osteotomy with a 20 × 2-mm Shannon burr.

Safe distances from the distal metatarsal head

Two key safe distances were defined, both measured from the most distal point of the first metatarsal head articular surface on lateral fluoroscopic imaging (Figure 10)^(14,16):

- **Dorsal arm:** a median safe distance of 25.6 mm. The dorsal arm of the osteotomy – where the Shannon burr exits the dorsolateral cortex – should be completed at or proximal to this distance from the metatarsal head tip, since osteotomies extending distal to this threshold approach the FDMA and its dorsal branch, increasing the risk of vascular injury.
- **Plantar arm:** a median safe distance of 23.9 mm. The plantar arm should likewise terminate at or proximally to this point relative to the metatarsal head, as extension beyond this threshold places the FPMA at increasing risk of injury.

These distances imply that the plantar landmark sits slightly more distal than the dorsal landmark, reflecting the differing courses of the FPMA and FDMA relative to the metatarsal neck. In a Chevron-type configuration, because the osteotomy is angulated (alpha angle ≈ 124 degrees)^(9,10,14), the dorsal and plantar limbs are geometrically distinct cuts, each requiring independent verification against its respective vascular landmark.

Safe lateral excursion of the Shannon burr

A complementary set of safety margins governs the lateral advancement of the Shannon burr beyond the lateral cortex exit point, reflecting the soft tissue clearance available between the cortical surface and the FDMA (dorsally) and FPMA (plantarly) (Figure 8C and D):

- **Dorsolateral excursion:** maximum 3.9 mm beyond the lateral cortex exit point. Beyond this distance, the FDMA and/or its dorsal branch are at risk of direct laceration.

- **Plantar-lateral excursion:** maximum 4.0 mm beyond the lateral cortex exit point. Beyond this limit, the FPMA and the lateral aspect of the FHB are at imminent risk.

Adherence to these excursion limits is particularly relevant given that the surgeon assesses burr position through a two-dimensional fluoroscopic projection; the dorsolateral and plantar-lateral soft tissue dimensions are not directly visualized intraoperatively, making pre-operative knowledge of these safe zones essential rather than supplementary^(14,16).

Extrapolating the safe-zone concept to the fourth-generation transverse osteotomy (META)

The safe distances described above were derived specifically from a chevron-type (angulated, V-shaped) osteotomy, in which the dorsal and plantar limbs diverge from a proximal apex and therefore exit the cortex at two distinct sagittal levels.

The META technique, by contrast, uses a single-plane transverse (non-angulated) osteotomy at the metatarsal neck, with only a minor 10-degree proximal-to-distal tilt introduced to compensate for burr-associated shortening⁽¹²⁾. Because the cut is performed in one plane rather than as two diverging limbs, the dorsal and plantar cortical exit points of a transverse osteotomy lie essentially at the same distance from the metatarsal head – unlike the chevron, where the geometry of the two arms separates the dorsal and plantar exit levels.

This distinction has a direct anatomical implication. If a transverse osteotomy is performed at approximately 26 mm from the most distal point of the first metatarsal head articular surface, it would simultaneously satisfy – within a single cut – both vascular safety thresholds identified by Carvalho et al.⁽¹⁴⁾: it lies at or proximal to the 23.9-mm plantar limit (protecting the FPMA) and closely approximates the

25.6-mm dorsal limit (protecting the FDMA and its dorsal branch). In effect, the transverse geometry of META removes the need to reconcile two separate arm-specific distances, since one plane can be positioned to respect both vascular landmarks concurrently (Figure 11).

We propose that this represents a logical anatomical extrapolation of the safe-zone concept originally described for Chevron-type (MICA) osteotomies to the fourth-generation transverse (META) technique, given that both procedures address the same extracapsular metaphyseal segment of the first metatarsal neck and rely on comparable burr dimensions (2.0-2.2 mm). However, this extrapolation has not yet been directly validated by micro-CT or perfusion studies performed on specimens using the transverse META configuration itself.

Future cadaveric micro-CT work replicating the META osteotomy – rather than the Chevron – would be valuable to confirm whether the 26-mm threshold, and the corresponding burr excursion limits (3.9 mm dorsolaterally, 4.0 mm plantar-laterally), hold true when applied to a single transverse cutting plane rather than an angulated one.

Practical landmarks and technical recommendations

The following technical recommendations are derived from the anatomical findings reviewed and are applicable to both third- and fourth-generation MIS techniques:

1. **Osteotomy apex placement.** Used for the MICA technique, the apex of the Chevron osteotomy (COA) should be positioned at the metatarsal neck flare^(9,10,14), verified fluoroscopically. A too-distal apex brings both osteotomy arms closer to the arterial plexus. On lateral fluoroscopy, the COA should appear at or proximally to the mid-neck level (Figure 10B).

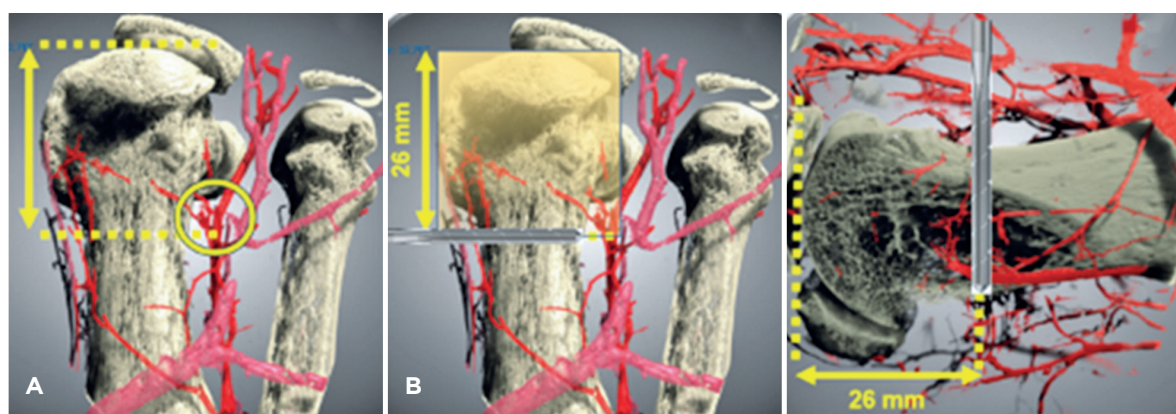


Figure 11. Theoretical safe position for performing minimally invasive surgery META osteotomy (Micro-CT images): (A) Anatomical reference landmarks, namely the bifurcation between the first plantar metatarsal artery (FDMA) and the lateral dorsal branch of the FDMA (inside the yellow circle), along with the most distal portion of the first metatarsal head. The theoretical safe position to complete the minimally invasive surgery META osteotomy is 26 mm, extending from the most distal point of the head of the first metatarsal proximally. (B) anterior view (C) lateral view.

2. **Shannon burr control.** The burr should be advanced with consistent pressure and withdrawn immediately upon tactile sensation of cortical exit. Continued advancement after cortical breakthrough directly violates the excursion safety margins. The 20 × 2-mm burr geometry provides a defined cutting width; awareness of its full width is necessary to prevent inadvertent injury at the far edge (Figure 8).
3. **Plantar arm caution.** The plantar arm carries the highest risk for FHB injury^(14,16). Maintaining a slight plantar-to-dorsal inclination during the plantar cut, rather than a purely horizontal trajectory, reduces the risk of engaging the FHB belly plantar to the osteotomy plane (Figure 8D/10B).
4. **Dorsal arm and nerve protection.** The dorsomedial nerve is most at risk when the incision portal or the burr trajectory deviates medially. The medial stab incision for the osteotomy should be placed in a strictly medial position at the metatarsal neck, avoiding any dorsalward displacement⁽¹⁶⁾. Malagelada et al.⁽³⁴⁾, in a cadaveric study, focused on increasing the safety of MIS hallux surgery, introduced the clock method and found that the dorsomedial nerve of the first toe was consistently located between 12 and 2 o'clock (0° and 60°, respectively) on the dorsomedial aspect of the hallux in right feet, and between 10 and 12 o'clock (300° and 360°, respectively) in left feet. Conversely, the dorsolateral nerve of the first toe was consistently found between 10 and 12 o'clock on the dorsolateral aspect of the hallux in the right feet and between 12 and 2 o'clock in the left foot^(33,34).

First metatarsal head cartilage and tibial posterior tendon

Although not explored in the literature, two additional points of caution merit attention in this review, as they may help minimize iatrogenic injury during MIS – specifically the MICA

and META techniques. In our cadaveric studies, we observed one instance of cartilage injury to the first metatarsal head resulting from excessive and inadvertent advancement of the drill, producing a 4.41 mm lesion (Figure 12A). A second point concerns the surgeon's attention to the drill's entry position: an entry angle directed too steeply from dorsal to plantar risks injury to the dorsal nerve, whereas an angle directed too steeply from plantar to dorsal risks injury to the insertion of the posterior tibial tendon (Figure 12B). Based on these observations, we recommend that both the surgical incision and the drill entry point be aligned parallel to the long axis of the first metatarsal.

Conclusion

Third- and fourth-generation MIS HV surgeries operate within an anatomical corridor containing structures invisible to the surgeon, requiring precise mastery of quantitative anatomical boundaries as the primary safeguard against iatrogenic injury. Cadaveric dissection and micro-CT vascular mapping studies establish that the Chevron osteotomy must be performed at a minimum distance of 25.6 mm (dorsal limb) and 23.9 mm (plantar limb) from the most distal point of the first metatarsal articular surface, with the excursion of the Shannon burr limited to 3.9 mm and 4.0 mm beyond the exit point on the lateral cortex. The fourth-generation META technique simultaneously addresses the FDMA and FPMA in a single transverse plane; for this technique, a unified safety distance of approximately 26 mm is proposed, although this measurement still awaits specific validation through anatomical and micro-CT studies. Neurological risk for both osteotomy generations centers on the dorsomedial nerve of the first toe. Biomechanical and radiographic equivalence between third- and fourth-generation constructs confirms that the choice of technique should be based on surgical training rather than alleged mechanical superiority, and that safe execution – regardless of geometry – depends on mastering the anatomical risk zones described in this review.

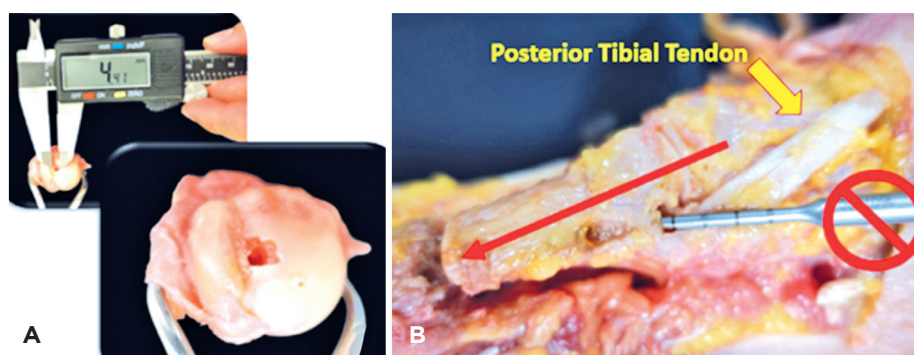


Figure 12. (A) Cartilage injury on the head of the first metatarsal resulting from excessive and inadvertent advancement of drills, measuring 4.41 mm on a digital caliper. (B) Dissection demonstrating the ideal drill entry trajectory, following the long axis of the first metatarsal (long red arrow). An entry angle that is excessively steep in the plantar-to-dorsal direction (prohibition symbol) carries a risk of injury to the posterior tibial tendon (yellow arrow).

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Special Article

Pain and functional disability related to foot and ankle among high heel users: Analytical cross-sectional study

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Abstract

Objective: To assess the intensity of pain and functional disability related to the foot and ankle among high-heel users.

Methods: A total of 208 female participants aged 18 years or older were included in this analytical cross-sectional study. Participants who met the inclusion criteria and provided informed consent were included in the study. Pain and functional disability were assessed using the Numeric Pain Rating Scale (NPRS) and Foot and Ankle Disability Index (FADI), respectively, and data regarding heel use, including duration and frequency per day and per week, were collected through a structured questionnaire. The data were not normally distributed; therefore, non-parametric tests were applied. Spearman correlation was used for correlation analysis, while multivariate multiple regression was applied to identify independent predictors of pain and functional disability.

Results: A total of 208 female participants were included, with a mean age of 24.25 ± 6.39 years and a mean BMI of 22.03 ± 3.25 kg/m². The mean NPRS score was 4.90 ± 2.21 , and the mean FADI score was 83.35 ± 18.27 . Pain distribution showed 13.9% with no pain, 29.3% with mild pain, 39.9% with moderate pain, and 16.8% with severe pain. NPRS and FADI scores showed significant variation ($p = 0.001$ and $p = 0.002$), while BMI was not significantly associated with either outcome. Multivariate multiple regression analysis demonstrated that age was the only significant independent predictor, with higher pain intensity ($\beta = 0.152$, $p < 0.001$) and lower functional ability ($\beta = -1.106$, $p < 0.001$), whereas BMI and heel-use characteristics showed no significant associations with either outcome.

Conclusion: Most participants experienced mild to moderate foot pain, with moderate pain being the most common category. Increasing age was significantly associated with higher pain intensity and greater functional disability, as reflected by higher NPRS scores and lower FADI scores. In contrast, BMI, heel height, and the frequency of daily and weekly heel use were not significantly associated with either outcome. Age was identified as a significant predictor of higher pain intensity and reduced functional ability, whereas heel-use characteristics did not predict either outcome.

Level of Evidence III; Analytical Cross-sectional Study.

Keywords: Ankle joint; Disability evaluation; Pain measurement; Tarsal bones.

Introduction

High-heeled shoes (HHSs) are becoming a growing trend among women as the trend continues to shift toward luxury. Although some claims suggest no significant change or even a reduction in muscle activity, high-heeled shoes have been associated with improper muscle use, leading to discomfort and occasional injuries⁽¹⁾. The ankle-foot complex changes more noticeably the higher the heel, triggering a chain reaction that affects the entire body, from the ankle and foot to the knee and even the spine⁽²⁾.

The human foot consists of 26 bones, including the calcaneus, talus, metatarsals, and phalanges, and is anatomically divided into the hindfoot, midfoot, and forefoot. The medial and lateral longitudinal arches play a crucial role in load transmission, shock absorption, and postural stability, while the foot is functionally organized into five rays, each comprising a metatarsal and its associated phalanges⁽³⁾.

High-heeled shoes are widely worn by women due to fashion trends and sociocultural influences, despite growing evidence of their adverse effects on musculoskeletal health⁽⁴⁾. From a

Study performed at the School of Allied Health Sciences, CMH Lahore Medical College & Institute of Dentistry (NUMS), Lahore, Pakistan.

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public health perspective, prolonged use of inappropriate footwear has been associated with foot pain, discomfort, and functional limitations⁽⁵⁾.

Biomechanically, elevation of the heel relative to the forefoot alters normal foot mechanics, resulting in increased plantar pressure over the forefoot and metatarsophalangeal joints⁽⁶⁾. This altered load distribution disrupts normal gait mechanics, reduces ankle range of motion, and increases stress across the lower extremities⁽⁷⁾.

Sustained use of HHSs is associated with increased muscle activation and fatigue, contributing to impaired postural control and musculoskeletal discomfort⁽⁸⁾. Additionally, prolonged heel elevation shifts the body's center of mass anteriorly, compromising balance and increasing the risk of instability and falls⁽⁹⁾.

Clinically, repetitive exposure to HHSs has been linked to forefoot pathology, abnormal load transmission, and chronic foot pain⁽¹⁰⁾. These biomechanical and postural adaptations may predispose wearers to long-term musculoskeletal disorders, emphasizing the need for footwear designs that balance aesthetic appeal with functional safety and musculoskeletal health⁽¹¹⁾.

The available literature shows that wearing HHSs has a noticeable impact on foot health and overall biomechanics, especially among working women. Several studies have reported a high prevalence of moderate to severe foot pain, with prolonged standing and increased heel height identified as key contributing factors^(12,13). Research conducted among young females has also highlighted foot-related problems, such as edema and callosities linked to high-heel use⁽¹⁴⁾. Among healthcare professionals, heel pain tends to increase with greater heel height and longer duration of wear⁽¹⁵⁾, and pain intensity has been found to be associated with heel height, duration of use, and body mass index (BMI)⁽¹⁶⁾. Similarly, occupational studies among nurses reveal a high occurrence of foot and ankle pain that affects both quality of life and work performance⁽¹⁷⁾. Biomechanical findings further suggest that habitual use of high heels alters gait patterns, reduces transverse arch height, and increases ground reaction forces⁽¹⁸⁾. Systematic reviews support these observations, linking high-heel use to musculoskeletal pain, hallux valgus, and an increased risk of injury, while the evidence regarding osteoarthritis remains limited⁽¹⁹⁾. Top of FormBottom of FormThese findings underscore the need for greater awareness of footwear choices and their potential risks and advocate preventive measures to mitigate foot-related issues among working women.

This study was conducted to address a contextual gap in the existing literature, as despite substantial global evidence on high-heel-related foot morbidity, limited data are available from South Asian populations, particularly Pakistan, where cultural practices, occupational demands, and footwear-use patterns differ from those reported in other regions and may influence risk profiles, highlighting the need for locally relevant evidence on foot pain associated with high-heel use in this population. The objective of this study is to assess the

intensity of pain and functional disability related to the foot and ankle among high-heeled users.

Methods

Study design and eligibility criteria

This was an analytical cross-sectional study and is reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology Statement (STROBE). This study was approved by the Institutional Review Board of the CMH LMC and IOD, Lahore, Pakistan.

The study was conducted in a medical college in Lahore, Pakistan. The study lasted four months after the synopsis was approved. All patients signed the informed consent form prior to initiating the study. All information and data collected were kept confidential. Participants remained anonymous throughout the study. The participant's personal identity and any personal information were hidden in all publications of this research project. The subjects were informed that there were no disadvantages or risks associated with the study procedure. The study population was female high-heeled users aged 18-35 years. They must be wearing high heels ≥ 2.5 inches at least 2-3 times per week for 2-3 hours per day⁽²⁰⁾. Patients with fractures, skin diseases such as dermatitis, degenerative diseases, RA, and any disease or deformity involving the ankle and foot are excluded. The sample size of 208 was calculated using the Cochrane formula (1977)⁽²¹⁾.

Study variables

Data were collected from females aged 18 to 35 years at CMH LMC and CMH Lahore who had signed the informed consent form and met the inclusion criteria. The non-probability convenience sampling technique was used to collect data from participants on the Foot and Ankle Disability Index (FADI) questionnaire and the Numeric Pain Rating Scale (NPRS).

- **Urdu form of the Foot and Ankle Disability Index (FADI-U):** This self-contained tool measures functional limitations associated with foot and ankle diseases. There were two subscales comprising a total of 26 items: 22 items in the activity subscale and 4 in the pain subscale. A five-point Likert scale (0 to 4) was used to score each item, with a total score of 104 points. The Cronbach's alpha coefficient (0.96-0.97) indicated excellent internal consistency⁽²²⁾.
- **NPRS:** The intra-class correlation coefficient (ICC) for all subjects was 0.76. Scores range from 0 to 10 points, with higher scores indicating greater pain intensity. The scale ranged from 0 (no pain at all) to 10 (worst imaginable pain). The NPRS has demonstrated good reliability, with high test-retest reliability, indicating that individuals tend to provide consistent ratings when asked to rate their pain intensity on separate occasions⁽²³⁾.

Outcome measures

The primary outcome of this study was to assess the intensity of pain and functional disability (FADI-U) related to the foot and ankle among high-heel users.

Statistical analysis

Descriptive statistics were used to describe the study population. Quantitative information, including age and heel height, was presented as mean + standard deviation (SD). Frequency and percentage were calculated from the collected data. Normality of the data was assessed using the Shapiro-Wilk test, and because the data were not normally distributed, nonparametric tests were used. To analyze all results, a 95% confidence interval was used. A p-value of less than 0.05 indicates statistical significance. Statistical analysis was performed using SPSS software version 26. Multivariate multiple regression analysis was conducted using R software version 4.5.2 to evaluate the effects of age, BMI, heel height, and the frequency of daily and weekly heel use on pain intensity and functional disability.

Results

The study sample was predominantly young adults aged 18-24 years (78.4%), with most participants having a normal BMI (68.3%), indicating a relatively homogeneous baseline anthropometric profile. High-heel use was frequent, with a mean daily wearing duration of 5.10 ± 1.62 hours and a weekly duration of 4.30 ± 1.85 days, reflecting regular exposure. The mean heel height was 4.15 ± 1.12 inches, with most participants wearing heels in the moderate range. Overall pain levels were moderate, with a mean NPRS score of 4.90 ± 2.21 , and the largest proportion of participants reported moderate pain (39.9%), as shown in Table 1.

A statistically significant age-related trend was observed in both pain and functional outcomes. Pain intensity increased progressively with age, as reflected by median NPRS scores (18-24: 3 [3], 25-35: 4 [3], > 35: 6 [4]; $p = 0.001$). In parallel, functional ability declined with increasing age, demonstrated by decreasing FADI scores across groups (18-24: 92 [23], 25-35: 88 [34], > 35: 70 [31]; $p = 0.002$), indicating worsening foot-related functional status with advancing age, as shown in Table 2.

Pairwise comparisons further highlighted that significant differences in pain intensity were primarily present between the youngest group and older participants, with 18-24 vs 25-35 years ($p = 0.012$) and 18-24 vs > 35 years ($p < 0.001$), while no significant difference was observed between 25-35 and > 35 years ($p = 0.236$). For functional ability, a statistically significant difference was observed only between 18-24 and > 35 years ($p < 0.001$), whereas other comparisons were not significant ($p > 0.05$), suggesting that functional decline is more evident at the extremes of the age distribution, as shown in Table 3.

Correlation analysis demonstrated a weak but statistically significant positive association between age and pain intensity (NPRS: $\rho = 0.286$, $p = 0.001$), alongside a weak negative correlation with functional ability (FADI: $\rho = -0.211$, $p = 0.002$), indicating increased pain and reduced function with advancing age. In contrast, BMI showed no statistically significant relationship with either pain ($\rho = 0.050$, $p = 0.474$) or functional outcomes ($\rho = 0.038$, $p = 0.584$), as shown in Table 4.

Table 1. Demographics of study participants (n = 208)

Variables	Mean $\pm$ Standard deviation	n (%)
Age (years)	24.25 $\pm$ 6.389	
18-24		163 (78.4)
25-35		22 (10.6)
> 35		23 (11.1)
Height (Inches)	63.40 $\pm$ 2.033	—
Weight (Kg)	57.20 $\pm$ 8.874	—
BMI (Kg/m ²)	22.03 $\pm$ 3.249	
< 18.5		27 (13.0)
18.5-24.9		142 (68.3)
25-29.99		38 (18.3)
> 30		1 (0.5)
Time of wearing high heels (Hours)/day	5.10 $\pm$ 1.62	—
Heel height (inches)	4.15 $\pm$ 1.12	—
Heel height categories (inches)	—	
2.5-3		42 (20.2)
3.1-4		68 (32.7)
4.1-5		57 (27.4)
5.1-6		31 (14.9)
> 6		10 (4.8)
Number of days wearing high heels/week	4.30 $\pm$ 1.85	—
Pain on NPRS	4.90 $\pm$ 2.21	—
Categories of pain	—	
No pain (0)		29 (13.9)
Mild (1-3)		61 (29.3)
Moderate (4-6)		83 (39.9)
Severe (7-10)		35 (16.8)

Values are presented as mean $\pm$ standard deviation or number (percentage). BMI: Body mass index; NPRS: Numerical Pain Rating Scale; kg/m²: kilograms per square meter.

Table 2. Summary measures of outcome variables

Outcome variables	Median (IQR)	p-value
Pain on NPRS	Median (Q3-Q1)	
18-24	3 (3)	0.001
25-35	4 (3)	
> 35	6 (4)	
Disability on FADI	Median (Q3-Q1)	
18-24	92 (23)	0.002
25-35	88 (34)	
> 35	70 (31)	

Data are presented as median (interquartile range). P-values were obtained using the Kruskal-Wallis test. NPRS: Numerical Pain Rating Scale; FADI: Functional Ankle Disability Index. A p-value < 0.05 was considered statistically significant.

Multivariate multiple regression analysis was conducted using R software version 4.5.2 to evaluate the effect of age, BMI, heel height, and the frequency of daily and weekly heel use on pain intensity and functional disability (Figures 1A, 1B, 2A, and 2B). The analysis showed that age was the only

Table 3. Pairwise comparison between age group of participants with FADI and NPRS (Kruskal-Wallis test)

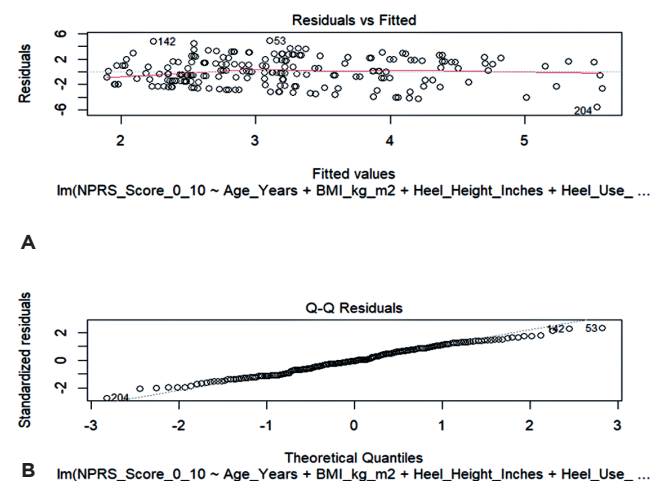
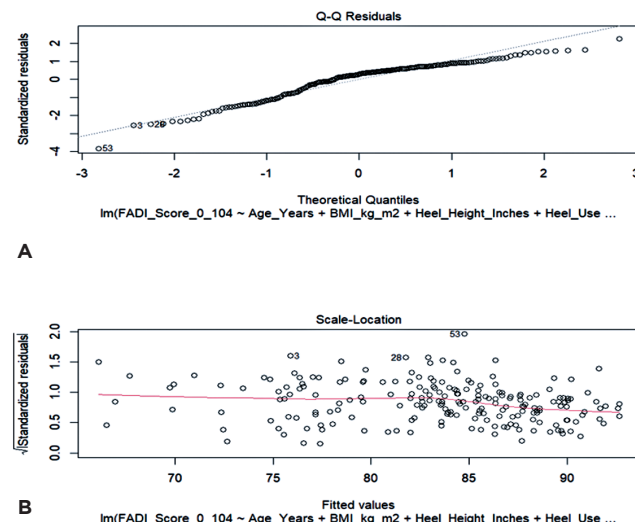
Outcome	Age group	Test statistic	p-value
FADI	> 35- (25-35) years	31.449	0.080
	> 35- (18-24) years	50.155	0.000
	(25-35) - (18-24) years	18.706	0.171
NPRS	(18-24) - (25-35) years	-34.147	0.012*
	(18-24) - > 35 years	-55.193	0.000*
	(25-35) - > 35 years	-21.046	0.236

Pairwise comparisons were performed using the Kruskal-Wallis test. Values represent test statistics and corresponding p-values. FADI: Functional Ankle Disability Index; NPRS: Numerical Pain Rating Scale. $p < 0.05$ indicates statistical significance.

Table 4. Correlation of age and body mass index with pain intensity (NPRS) and functional ability (FADI)

Independent variable	Outcome measure	Spearman's ρ	p-value
Age (years)	NPRS	0.286	0.001*
	FADI	-0.211	0.002*
Body mass index (kg/m ²)	NPRS	0.050	0.474
	FADI	0.038	0.584

*Spearman's rank correlation coefficient (ρ). Lower FADI scores indicate greater functional disability. Statistically significant at $p < 0.05$.

**Figure 1.** Multivariate multiple regression analysis for NPRS (0-10).**Figure 2.** Multivariate multiple regression for FADI score (0-104).

variable significantly associated with both outcome measures. An increase in age was linked with higher NPRS scores ($\beta = 0.152$, $p < 0.001$), indicating greater pain intensity, and lower FADI scores ($\beta = -1.106$, $p < 0.001$), reflecting reduced foot and ankle function.

For the NPRS model, hours of daily heel use showed a borderline association with pain intensity ($\beta = 0.203$, $p = 0.087$), whereas BMI, heel height, and weekly hours of heel use did

not show significant relationships with NPRS scores after adjustment. The overall regression model for NPRS was statistically significant ($F = 6.395$, $p < 0.001$) with an adjusted R^2 of 0.115, as shown in Table 5.

In the FADI model, variables other than age were not significantly associated with functional disability. The model remained statistically significant overall ($F = 4.397$, $p < 0.001$) and explained 7.6% of the adjusted variance in FADI scores.

These findings indicate that advancing age may play an important role in increasing foot pain and decreasing functional ability among women who wear high heels, as shown in Table 6.

Discussion

Although high heels remain widely used in women's fashion, their impact on foot and ankle health remains clinically relevant. In the present study, age was significantly associated with both increased pain and reduced functional ability, while BMI showed no significant relationship with either outcome. Multivariate analysis further confirmed age as the only independent predictor of pain ($\beta = 0.152$, $p < 0.001$) and functional disability ($\beta = -1.106$, $p < 0.001$), whereas heel-related exposure variables, including heel height and duration of use, were not significant after adjustment.

Our findings are consistent with previous research demonstrating an association between high-heel use and pain in the ankle and foot^(24,25). However, in contrast to the findings reported by Qurrat-ul-Ain et al.⁽²⁵⁾, no significant relationship was observed between heel height and foot discomfort in the present study, suggesting that heel height alone may not be the primary determinant of symptoms.

Females wearing heels ≥ 2.5 inches for limited durations predominantly reported mild to moderate pain. Similar findings have been reported previously, in which foot discomfort

was common among high-heel users despite a statistically non-significant relationship between heel height and pain⁽²⁴⁾. These observations suggest that factors such as the duration and frequency of exposure may have a greater influence on pain than heel height alone^(23,24).

Most participants in the present study reported either no discomfort or moderate discomfort, which is consistent with previous literature reporting a considerable prevalence of foot pain among high-heel users^(26,27). The absence of a significant association between heel height and pain further suggests that individual biomechanical characteristics, foot morphology, and pain tolerance may substantially contribute to symptom presentation^(24,26).

Previous biomechanical studies have demonstrated that high-heel use alters gait kinematics, posture, balance, and foot stability⁽²⁸⁾. Despite these reported biomechanical alterations, most participants in the present study experienced no difficulty standing, walking, or performing routine daily activities, suggesting possible adaptation among habitual users.

Functional outcomes in our sample, reflected by relatively higher FADI scores, indicated lower levels of disability despite the presence of mild to moderate pain. Comparable NPRS findings have also been observed in earlier studies investigating high-heel users, indicating that pain may occur even when functional impairment remains relatively minimal^(23,25).

Table 5. Multivariate multiple regression for NPRS score (0-10)

Variables	β	SE	t	p
(Intercept)	-0.63339	1.66795	-0.380	0.7045
Age (Years)	0.15226	0.02907	5.237	4.08e-07***
BMI (kg/m ²)	0.01365	0.04646	0.294	0.7692
Heel Height (Inches)	-0.35178	0.30880	-1.139	0.2560
Heel Use Hours/Day	0.20300	0.11800	1.720	0.0869.
Heel Use Days/Week	0.07843	0.18385	0.427	0.6701

Model Statistics: $R^2 = 0.1367$ | Adjusted $R^2 = 0.1153$ | $F(5,202) = 6.395$ | $p = 1.542e-05$ | Residual Standard Error = 2.116 (df = 202). β = regression coefficient; SE = standard error; t = t-statistic; p = p-value; R^2 = coefficient of determination; Adjusted R^2 = adjusted coefficient of determination; F = F-statistic; NPRS = Numeric Pain Rating Scale; BMI = Body Mass Index. Significance notation: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.1$.

Table 6. Multivariate multiple regression for FADI score (0-104)

Variables	β	SE	t	p
(Intercept)	96.8446	13.8482	6.993	3.85e-11***
Age (Years)	-1.1063	0.2414	-4.583	8.01e-06***
BMI (kg/m ²)	0.2317	0.3858	0.601	0.549
Heel Height (Inches)	3.1077	2.5638	1.212	0.227
Heel Use Hours/Day	-0.9113	0.9797	-0.930	0.353
Heel Use Days/Week	-0.1585	1.5264	-0.104	0.917

Model Statistics: $R^2 = 0.09816$ | Adjusted $R^2 = 0.07584$ | $F(5,202) = 4.397$ | $p = 0.0008018$ | Residual Standard Error = 17.57 (df = 202). β = regression coefficient; SE = standard error; t = t-statistic; p = p-value; R^2 = coefficient of determination; Adjusted R^2 = adjusted coefficient of determination; F = F-statistic; FADI = Foot and Ankle Disability Index; BMI = Body Mass Index. Significance notation: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, $p < 0.1$.

Similarly, previous evidence has shown that high-heel use does not significantly reduce physical activity levels or increase fatigue among working women⁽²⁹⁾. Consistent with these findings, most participants in the present study were able to perform daily physical activities without major limitations.

The present findings are also comparable to the work of Kaur and Chitkara, who reported reduced dynamic stability among habitual high-heel wearers using the Four-Square Step Test⁽³¹⁾. While their findings highlighted impaired balance control during functional movement, the present study demonstrated that, after adjustment, heel-related variables were not independently associated with pain or functional disability.

From a clinical perspective, the findings suggest that prolonged and habitual high-heel use may contribute to foot discomfort and biomechanical stress in some individuals. Educating women, particularly those who wear high heels for occupational purposes, about appropriate footwear practices, regular rest periods, and foot care may help reduce discomfort and functional strain. Additionally, the absence of an independent association between heel height and pain after adjustment indicates that individual factors and cumulative exposure may be more important contributors than heel height alone.

Limitations

The analytical cross-sectional design does not permit establishing causal relationships between high-heel use and foot and ankle outcomes. The study was conducted in a single medical setting using convenience sampling, with a predominantly young sample, which may have influenced the multivariate multiple regression findings and limited the generalizability of the results to older or occupational populations. Potentially relevant factors, such as walking surface, footwear fit, gait characteristics, and shoe design features, were not controlled for in the present study. The lack of a non-high-heel user group limits the ability to

compare outcomes with individuals who do not wear high heels, thereby restricting the interpretation of results in a broader comparative context. The FADI may not fully capture all biomechanical aspects associated with high-heel use.

Strengths of the study and clinical relevance

A key strength of this study is its analytical cross-sectional design with multivariate modeling, which enabled the simultaneous evaluation of multiple independent variables influencing pain and functional disability. The independent variables included age, BMI, heel height, frequency of daily and weekly heel use, while the dependent variables were pain intensity, measured by the NPRS, and functional disability, measured by the FADI. The use of validated outcome measures enhances the reliability and clinical applicability of the findings, and adjustment for multiple covariates strengthens the internal validity of the results.

Clinically, the findings are relevant, as they demonstrate that age is a consistent predictor of both higher pain intensity and reduced functional ability among high-heel users, whereas heel-use characteristics and BMI did not show independent associations. This highlights the importance of incorporating age-related musculoskeletal considerations into clinical assessment and decision-making rather than relying solely on footwear exposure patterns.

Conclusion

Most participants experienced mild to moderate foot pain, with moderate pain being the most common category. Increasing age was significantly associated with higher pain intensity and greater functional disability, as reflected by higher NPRS scores and lower FADI scores. In contrast, BMI, heel height, and the frequency of daily and weekly heel use were not significantly associated with either outcome. Age was identified as a significant predictor of higher pain intensity and reduced functional ability, whereas heel-use characteristics did not predict either outcome.

Authors' contributions: Each author contributed individually and significantly to the development of this article: KI* (<https://orcid.org/0009-0003-2684-3989>) Data collection; NM * (<https://orcid.org/0000-0002-7667-1869>) Conceived and planned the activities that led to the study, interpreted the results of the study, formatting of the article; RA * (<https://orcid.org/0000-0002-7667-1869>) Statistical analysis; PW * (<https://orcid.org/0000-0002-4833-0928>) Participated in the review process, approved the final version. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) .

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Review

Perception and clinical outcomes of total ankle replacement and contralateral arthrodesis for ankle osteoarthritis: A narrative review

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Abstract

Objective: To evaluate the current evidence on perception, satisfaction, and functional outcomes in patients with bilateral ankle osteoarthritis treated with a total ankle replacement on one limb and contralateral arthrodesis.

Methods: This narrative review, conducted as a qualitative, descriptive thematic synthesis in accordance with the Scale for the Assessment of Narrative Review Articles, searched four electronic databases between March and April 2026 with no restriction on publication year. The intra-individual design was intended to reduce demographic and lifestyle heterogeneity, although it does not eliminate biomechanical interdependence between limbs.

Results: Three studies met the inclusion criteria, with mean follow-up ranging from 2 to 6.2 years across cohorts. Both procedures achieved comparable pain relief. Total ankle replacement preserved sagittal-plane motion, producing higher functional scores and a more intuitive, physiologic gait, whereas arthrodesis offered a stable weight-bearing base but restricted dorsiflexion, induced compensatory midfoot kinematics, and increased the cognitive burden of monitoring the environment to prevent falls. Patient-reported and general health measures showed comparable satisfaction between sides; replacement complications were predominantly mechanical, whereas arthrodesis complications were predominantly biological. The hybrid strategy was reported as more cost-effective than bilateral arthroplasty.

Conclusion: In bilateral end-stage ankle osteoarthritis, combining a replacement on one limb with a contralateral arthrodesis allows patients to alternate limb use according to task; standardized, long-term prospective studies are required to confirm these observations.

Level of Evidence V; Narrative review.

Keywords: Arthroplasty; Replacement, Ankle; Arthrodesis; Patient satisfaction; Gait.

Introduction

Ankle osteoarthritis is a chronic degenerative disease in which recurrent microtrauma drives progressive cartilage loss, ultimately producing persistent arthralgia and mechanical dysfunction⁽¹⁾. Symptomatic ankle osteoarthritis affects approximately 1% to 4% of adults and remains a recognized clinical challenge⁽²⁾. Unlike hip or knee osteoarthritis, which are predominantly primary or age-related, 75% to 80% of ankle cases are post-traumatic, arising from complex fractures

or chronic ligamentous instability⁽³⁾. Because it commonly affects a younger population after trauma, its long-term socioeconomic and functional burden is substantial^(4,5).

Ankle arthrodesis remains a definitive option for end-stage degeneration, providing predictable pain relief, high osseous union rates (greater than 90%), long-term durability⁽⁶⁾, and reported patient satisfaction of 77%⁽⁷⁾. Approximately 70% of patients require no subsequent intervention, with a lower revision profile than total ankle replacement⁽⁸⁾. However,

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these benefits are tempered by permanent loss of tibiotalar motion and compensatory gait kinematics, which precipitate moderate-to-severe subtalar arthritis in about 15% of cases⁽⁹⁾. Absolute contraindications include active infection, severe peripheral vascular disease, and significant ipsilateral hindfoot arthritis⁽³⁾.

Total ankle replacement is an effective alternative for end-stage disease, offering significant pain reduction and superior short- to medium-term function⁽¹⁰⁾. Its principal advantage is preserving sagittal-plane motion, which reduces stress on adjacent joints and yields patient satisfaction of 81%⁽⁷⁾. Modern third-generation implants show 10-year survivorship of 78%⁽¹¹⁾, with a comparable rate of 86.6% reported over a mean follow-up of 7.75 years in an independent multicenter cohort⁽¹²⁾. Contraindications include active infection, talar avascular necrosis, Charcot arthropathy, and critical vascular or bone insufficiency⁽¹³⁾.

Before arthroplasty, and even during the first generations of ankle implants, arthrodesis was the gold standard for eliminating pain at the cost of motion⁽¹⁴⁾. Whereas replacement seeks to preserve joint kinematics⁽¹⁴⁾, the choice between arthrodesis and arthroplasty remains debated. Performing both procedures in the same patient offers a valuable methodological opportunity: the patient could serve as an intra-individual control, allowing direct comparison of subjective function and satisfaction while minimizing demographic and lifestyle biases inherent to independent-group studies⁽¹⁴⁻¹⁶⁾. Although compensatory gait adaptations after either procedure mean the two limbs are not fully biomechanically independent⁽¹⁷⁾, each patient's simultaneous, first-hand experience of both a prosthetic and a fused ankle offers a uniquely informative perspective on perception, satisfaction, and quality of life.

The objective of this narrative review is to evaluate current evidence on perception, satisfaction, and functional outcomes in patients undergoing simultaneous contralateral total ankle replacement and arthrodesis for bilateral ankle osteoarthritis.

Methods

As this is a narrative review of previously published literature, Institutional Review Board approval was not required. This study was conceived as a narrative review; however, given the scarcity of literature directly addressing bilateral ankle osteoarthritis managed with contralateral total ankle replacement and arthrodesis, a structured, systematic-style search and selection process was adopted to enhance transparency and reproducibility. Given the limited number and heterogeneity of the studies identified, a formal systematic review with risk-of-bias assessment and meta-analysis was not considered methodologically appropriate; findings are therefore presented as a narrative synthesis.

A structured literature search was conducted across four electronic databases – PubMed (MEDLINE), Embase, Scopus, and LILACS (Virtual Health Library) – between March and April 2026, with no restriction on publication

year. Records were limited to English- or Spanish-language publications. The search employed Boolean operators using the following terms: ankle, replacement, arthroplasty, prosthesis, arthrodesis, fusion, fused, bilateral, contralateral, simultaneous, concurrent, concomitant, and combined. The comprehensive search yielded 631 records.

Studies were eligible for inclusion if they reported on patients treated with ankle arthrodesis on one limb and total ankle replacement on the contralateral limb for bilateral ankle osteoarthritis, were of any human study design (case reports, case series, retrospective or prospective cohorts, qualitative studies), and reported at least one variable related to patient perception, satisfaction, or functional outcome. Studies were excluded if they analyzed ankle replacement or arthrodesis as isolated procedures, reported conversion of failed arthroplasty to arthrodesis or vice versa, addressed ipsilateral combined procedures without contralateral counterpart, or did not provide extractable outcome data relevant to the review objective. The reference lists of the three included studies were manually searched for additional relevant citations. Forward citation tracking was not performed, and unpublished studies and grey literature were not included.

Title/abstract screening and full-text eligibility assessment were performed independently by two authors (VH, LDCR); disagreements were resolved by discussion between reviewers, and any unresolved disagreement was adjudicated by a third author (CAS). Three studies met all inclusion criteria and are detailed in Table 1. The selection process is illustrated in Figure 1. Consistent with the narrative review design, this review was not registered in a protocol database, and no formal risk-of-bias assessment or certainty-of-evidence appraisal was performed; instead, studies were characterized by design type, sample size, follow-up duration, and outcome measurement tools used. Dependent variables and summary measures were not pooled quantitatively due to substantial clinical and methodologic heterogeneity. Results are presented through qualitative thematic synthesis organized by clinically relevant domains: gait kinematics and functional outcomes, patient satisfaction and perception, complication and reintervention rates, and cost-effectiveness.

Results

Comparative impact on gait patterns

While both procedures significantly reduce chronic pain, their kinematic profiles differ. Total ankle replacement more closely resembles physiologic walking by preserving sagittal-plane motion^(14,16); replacement limbs retain significantly greater total sagittal motion during the transition between dorsiflexion and plantarflexion, supporting superior performance in dynamic tasks such as navigating stairs and higher functional scores⁽¹⁶⁾.

In contrast, arthrodesis eliminates tibiotalar mobility, producing a rigid gait with compensatory hypermobility of adjacent midfoot joints⁽¹⁶⁾. Although patients value the fused ankle for prolonged standing, restricted dorsiflexion and

Table 1. Characteristics of the studies included in the review (N = 3 studies, 38 patients)

Author (year)	Title	Study design	Patients (n)	Follow-up	Outcome measures/instruments
Chen et al. (2022)	Simultaneous total ankle replacement and contralateral ankle arthrodesis for bilateral ankle osteoarthritis: a retrospective study focused on clinical outcomes and cost-effectiveness	Retrospective	12	Minimum 2 years (assessed at 4 months, 1 year, and 2 years)	VAS (pain); goniometric ROM; AOFAS ankle-hindfoot score; 5-grade satisfaction questionnaire
Conlin et al. (2021)	Living with both a total ankle replacement and an ankle fusion: a qualitative study from the patients' perspective	Qualitative	10	Minimum 1 year since most recent ankle reconstruction (mean 4.6 years)	Semi-structured qualitative interviews with thematic content analysis; AOS scores collected only to characterize the sample
Henricson et al. (2016)	Total ankle replacement and contralateral ankle arthrodesis in 16 patients from the Swedish Ankle Registry: self-reported function and satisfaction	Retrospective	16	Mean 74 months (12-145) for the prosthesis side; mean 66 months (12-156) for the arthrodesis side	SEFAS (0-48); 5-grade satisfaction questionnaire (Likert)

AOFAS: American Orthopaedic Foot and Ankle Society; AOS: Ankle Osteoarthritis Scale; ROM: range of motion; SEFAS: Self-Reported Foot and Ankle Score; VAS: visual analogue scale.

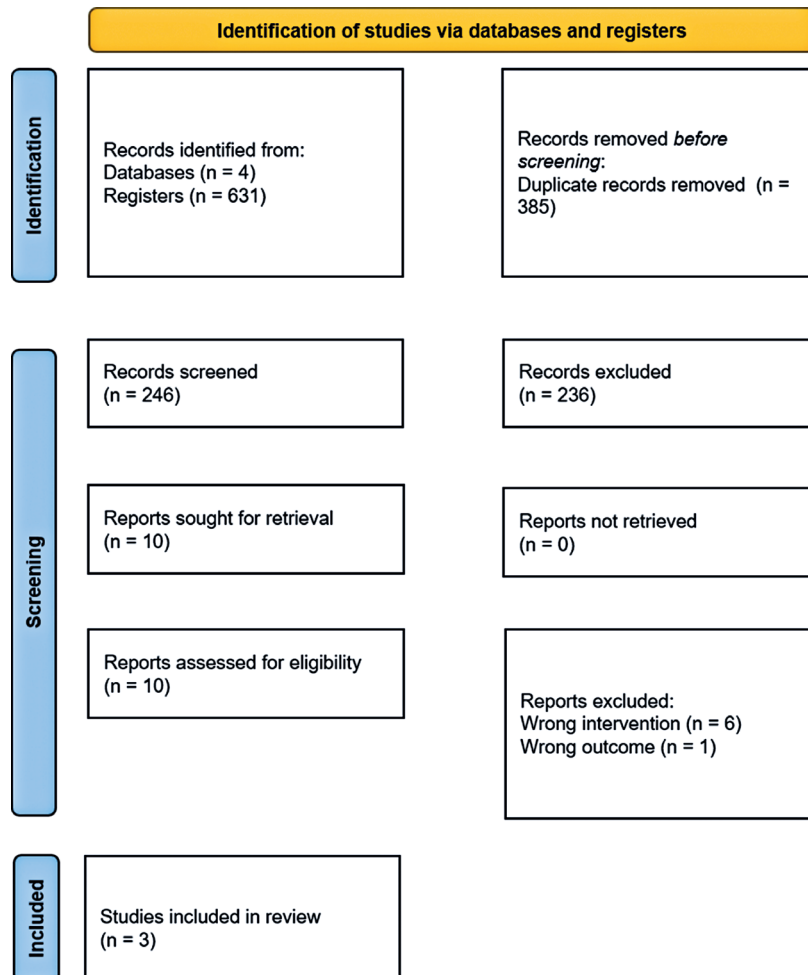


Figure 1. Flow diagram of study identification, screening, and selection, based on the PRISMA 2020 flow diagram template⁽¹⁸⁾. From 631 records retrieved across four databases, 3 studies met the inclusion criteria.

plantarflexion often cause a catching sensation or tripping on irregular surfaces⁽¹⁵⁾. This compromises global equilibrium and requires constant environmental vigilance, as patients must visually monitor each step to compensate for obstacles the ankle can no longer accommodate⁽¹⁶⁾.

In a qualitative study of 10 patients living with both procedures, participants described a marked preference for the physiologic feel of replacement, characterized as intuitive and fluid, whereas the fused ankle was perceived as a rigid structure requiring compensatory limb or torso movement to turn⁽¹⁵⁾. Patients with one replacement and one fusion often alternate the lead foot by task, using the flexible side for pivoting or descending steps and the stable side for weight-bearing⁽¹⁵⁾. Despite occasional apprehension that the implant might give way on uneven surfaces, these qualitative accounts describe a subjective preference for replacement, attributed to the reduced cognitive burden of gait monitoring⁽¹⁵⁾.

Reintervention and complication rates

Current evidence indicates no clear difference in overall reintervention between the two procedures, although failure mechanisms differ markedly⁽¹⁴⁾. All-cause reoperation rates tend to be higher after replacement⁽¹⁶⁾; revisions are primarily mechanical, including polyethylene wear or fracture, aseptic loosening, and component instability^(19,20).

Complications of arthrodesis are predominantly biological, centered on consolidation failure (non-union) and accelerated secondary osteoarthritis of adjacent joints from compensatory load transfer⁽⁹⁾. Replacement does not appear to compromise neighboring joint biology; combined subtalar fusion and replacement achieves a high fusion rate of 92%⁽²¹⁾, and cohorts undergoing simultaneous bilateral surgery (one replacement, one fusion) reported no short-term revisions in either limb⁽¹⁶⁾.

Although registry data suggest a higher long-term mechanical revision risk for replacement, this is frequently offset by superior function: a greater sagittal arc of motion, higher functional scores, and a more physiologic gait. Arthrodesis provides stable support but is associated with stiffness-related limitations and midfoot overload⁽¹⁴⁾. For most patients, the functional benefits of preserved mobility outweigh the mechanical risk, and patients generally prioritize physiologic mobility over the limitations imposed by fusion rigidity⁽¹⁵⁾.

Quality-of-life outcomes and functional scales

Patients undergoing both procedures report significant improvement over their preoperative state, although outcomes vary by metric⁽¹⁶⁾. On objective clinical scales, patients consistently assign higher scores to the replacement limb, reflecting greater range of motion and functional capacity⁽¹⁴⁾.

The distinction narrows with patient-reported outcome measures and general health surveys. Swedish Ankle Registry data show a median Self-Reported Foot and Ankle Score of 32 (range, 16-44) for replacement and 27 (range, 14-47)

for arthrodesis, a difference that did not reach statistical significance ($p = 0.271$), suggesting comparable function in daily activities⁽¹⁴⁾. The 12-Item Short Form Survey showed substantial and equivalent improvement in physical and mental components for both techniques⁽¹⁴⁾.

No bias related to limb dominance or laterality was reported; preference was driven primarily by kinematic flexibility. Most patients expressed a subjective inclination toward the replacement side for its more natural motion while valuing the fused side for reliable stability and weight-bearing. Once pain is eradicated, both procedures reach remarkably similar satisfaction, indicating a subjective equilibrium between the sturdiness of a fusion and the mobility of a prosthesis⁽¹⁵⁾.

Factors influencing technique selection

Technique selection rests on a multidimensional balance of functional demand, biological constraints, and long-term mechanical stability. Activity level is a primary determinant: replacement is typically favored for patients prioritizing physiologic gait and dynamic flexibility, whereas arthrodesis is preferred for high physical demands or occupations requiring prolonged weight-bearing, where a strong, stable base is essential^(3,11).

Age and bone stock further influence the decision; the risks of mechanical wear and implant failure must be weighed against life expectancy⁽¹¹⁾, and coronal alignment and soft-tissue integrity are technical prerequisites for arthroplasty to prevent premature loosening⁽¹³⁾. Arthrodesis offers a more reliable framework for rigid correction of severe deformity, yet replacement remains viable in complex, multi-joint scenarios when combined with auxiliary procedures such as subtalar fusion, which maintains a 92% consolidation rate⁽²¹⁾. In bilateral end-stage disease, the hybrid approach has been reported as 34.1% more cost-effective than bilateral arthroplasty while achieving comparable pain relief and global functional recovery⁽¹⁶⁾.

Discussion

This narrative review examined the emerging evidence for combining total ankle replacement with contralateral arthrodesis in bilateral end-stage ankle arthrosis. Based on a limited evidence base of three studies and 38 patients, predominantly retrospective and with short follow-up, the hybrid approach appears to be a promising option for appropriately selected patients: it has been reported as 34.1% more cost-effective than bilateral replacement while maintaining equivalent satisfaction⁽¹⁶⁾, and in cases complicated by hindfoot degeneration, combining replacement with subtalar fusion is a reasonable alternative to tibiototalcalcaneal arthrodesis⁽²¹⁾. Nonetheless, the cost-effectiveness estimate derives from a single retrospective cohort within one healthcare system and is highly sensitive to implant costs, reimbursement structures, revision rates, and country-specific economic factors, and should not be generalized to other settings. These findings should be

regarded as hypothesis-generating rather than a basis for definitive treatment recommendations.

A clinical decision algorithm is proposed for bilateral disease (Figure 2). The surgeon should balance biomechanical optimization with economic sustainability, tailoring management to each limb rather than enforcing strict symmetry. For patients prioritizing natural gait and dynamic flexibility, isolated replacement remains preferred for its physiologic kinematics⁽¹⁰⁾; isolated arthrodesis provides a more reliable, stable base for high physical demands or severe structural instability⁽⁴⁾.

Bilateral arthrodesis remains a high-satisfaction option for end-stage disease, providing substantial pain relief and functional improvement⁽¹⁴⁾. However, its gait burden should not be underestimated. Permanent motion loss forces reliance on compensatory midfoot and hindfoot hypermobility, producing gait abnormalities more pronounced than after unilateral procedures; bilateral patients report difficulty with inclines, stairs, and uneven surfaces and score significantly lower in social-functioning domains despite effective pain relief^(15,22). The procedure also carries an approximately 9% non-union rate and the risk of progressive adjacent-joint arthritis⁽¹⁴⁾. Notably, a recent 25-year national population

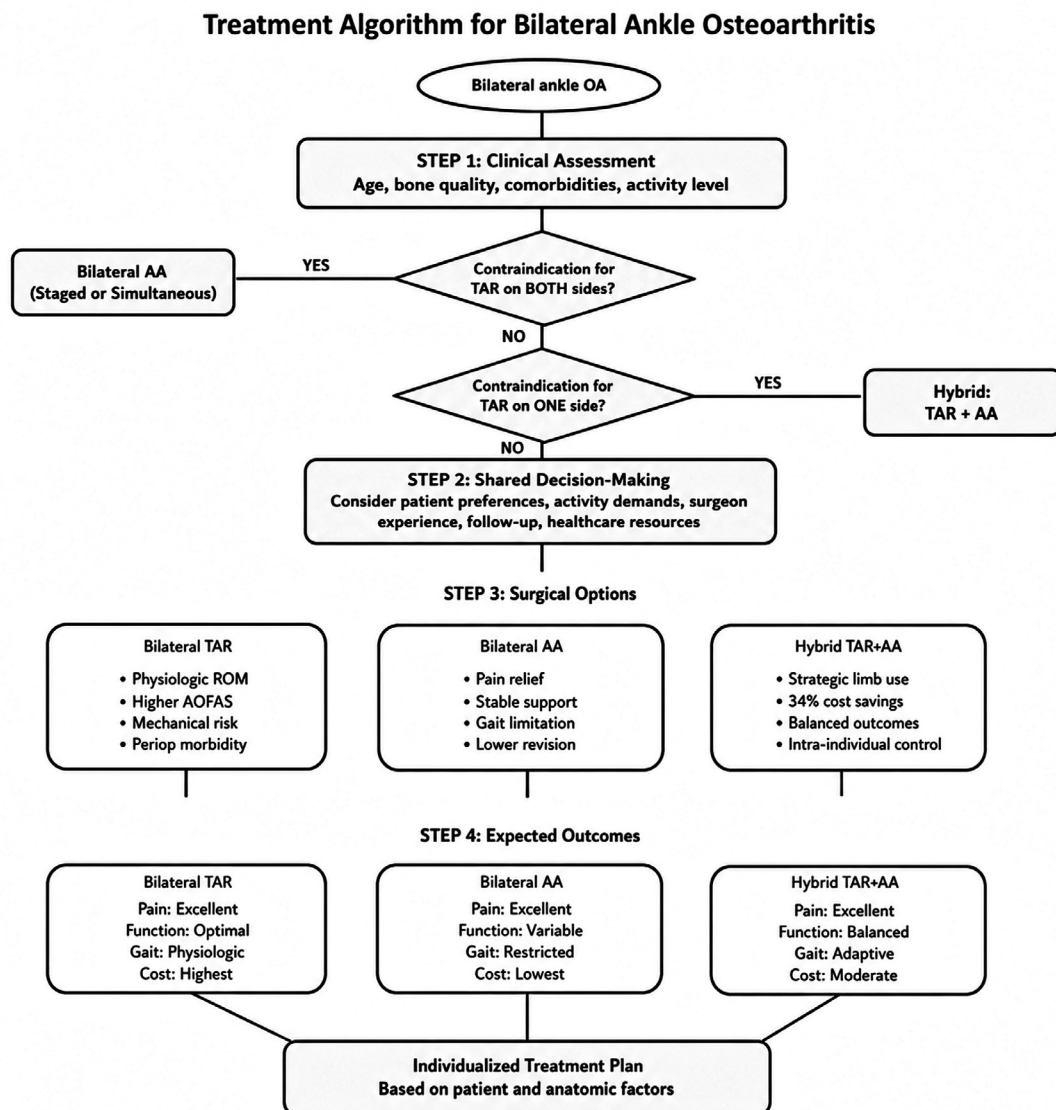


Figure 2. Proposed treatment decision algorithm for bilateral ankle osteoarthritis, based on the authors' clinical expertise and interpretation of the reviewed literature; it does not represent an evidence-based ranking of options, given the limited number of studies included. AA: Ankle arthrodesis; AOFAS: American Orthopaedic Foot and Ankle Society score; OA: Osteoarthritis; ROM: Range of motion; TAR: Total ankle replacement.

study of over 40,000 patients found no significant difference in the long-term risk of subsequent hindfoot fusion between arthrodesis and replacement (8.64% vs 6.82%, respectively), suggesting that this biomechanical burden may not translate into a proportionally higher rate of adjacent joint failure over time⁽²³⁾. These functional costs should nonetheless remain central to shared decision-making.

Bilateral replacement, performed simultaneously or sequentially, is a highly effective alternative, yielding long-term functional recovery comparable to unilateral procedures, with midterm implant survival of 91% to 100%; however, perioperative complication rates remain substantial, between 22% and 24%⁽²⁴⁾. Overall, replacement excels at restoring sagittal range of motion and functional scores, whereas arthrodesis is equally effective for isolated pain relief⁽¹⁴⁾. A balanced hybrid approach uses replacement to preserve pivoting and flexibility on one side and arthrodesis for prolonged weight-bearing and stability on the other, optimizing global function^(15,16).

Intra-individual controls are a valuable methodological strategy but are not a definitive solution to the debate, because the limbs do not function in isolation; patients develop compensatory motor strategies that introduce biomechanical bias. Generalizability is further limited by small samples – 10 to 16 patients per study – stemming from the rarity of bilateral pathology treated with mixed techniques, which risks missing subtle clinical differences. Unfortunately, several clinical comparisons and the reported cost-effectiveness estimate (34.1%) rely predominantly on a single retrospective study with only 12 patients⁽¹⁶⁾, limiting the robustness and generalizability of these findings.

A lack of technical standardization, with diverse prosthesis designs and varying fixation methods, introduces additional confounding. The search was also restricted to English- and Spanish-language publications, which may have excluded relevant studies published in other languages. Predominantly retrospective designs limit control of selection bias, while short follow-up (1-2 years) fails to capture long-term survivorship or adjacent-joint degeneration. Bilateral gait biomechanics, return to sport or physical activity level, and revision of a replacement following contralateral arthrodesis remain largely unaddressed in the literature specific to this population, and specific fourth-generation implant outcomes fall outside the scope of the included studies. These gaps, together with the limited number of studies and absence of randomized prospective trials, should be considered when interpreting the present findings and point to clear directions for future research.

In conclusion, preliminary evidence from a limited number of studies suggests that a hybrid total ankle replacement and contralateral arthrodesis approach may allow patients to use replacement flexibility for dynamic tasks and balance while relying on arthrodesis stability for heavy weight-bearing, potentially representing a cost-effective alternative to bilateral arthroplasty in appropriately selected patients. Rather than mutually exclusive, the two procedures appear complementary, although this observation is drawn from a small, methodologically heterogeneous evidence base. These observations should be interpreted with caution and used to inform future randomized controlled trials and prospective cohort studies evaluating modern implant survivorship, cognitive load, validated patient-reported measures of balance and physiologic feel, and reciprocal mechanical stress between reconstructed limbs.

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Systematic Review

Surgical approaches to hallux rigidus: a systematic review of arthrodesis and alternative techniques

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Abstract

Objective: To analyze and compare the clinical outcomes of arthrodesis versus alternative surgical techniques for hallux rigidus in adults.

Methods: A systematic literature review was conducted in accordance with PRISMA guidelines. Electronic searches were performed in major databases to identify studies reporting surgical outcomes of arthrodesis and alternative techniques for hallux rigidus. Study characteristics, surgical techniques, reported outcomes, and complications were qualitatively synthesized.

Results: The included studies were predominantly retrospective and demonstrated substantial heterogeneity in surgical techniques, outcome measures, and follow-up durations. Reported outcomes varied widely across procedures, and direct comparative evidence was limited.

Conclusions: Current evidence on the surgical management of hallux rigidus is limited by study design, heterogeneity, and risk of bias. The available literature does not allow definitive conclusions regarding the superiority or equivalence of arthrodesis and motion-preserving procedures. High-quality comparative studies are needed to better define the role of alternative techniques in the treatment of hallux rigidus.

Level of Evidence III; Systematic Review.

Keywords: Hallux rigidus; Arthrodesis; Arthroplasty; Systematic review.

Introduction

Hallux rigidus is a common degenerative condition of the first metatarsophalangeal joint^(1,2). Arthrodesis is widely regarded as the reference surgical procedure for advanced disease, while motion-preserving techniques, including interpositional arthroplasty, have gained increasing attention in recent years^(1,3).

Several systematic reviews have evaluated surgical management of hallux rigidus; however, most have highlighted the predominance of low-quality studies, limited comparative data, and the absence of robust randomized controlled

trials^(4,5). As a result, uncertainty persists regarding the relative effectiveness, complication profiles, and indications for arthrodesis versus motion-preserving techniques⁽³⁻⁵⁾.

The primary objective of this systematic review was to qualitatively synthesize the available evidence on surgical outcomes of arthrodesis and alternative procedures for hallux rigidus, focusing on reported clinical results and complications. The working hypothesis was that current literature does not provide sufficient high-quality comparative evidence to support definitive conclusions regarding the superiority or equivalence of surgical techniques.

Study performed at the Hospital Santa Izabel, Salvador, BA, Brazil.

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Therefore, this systematic review aimed to analyze and compare the clinical outcomes of arthrodesis versus alternative surgical techniques for hallux rigidus in adults. Specific aims included: identifying the main outcomes reported in the literature; comparing complication and reoperation rates between procedures; assessing patient satisfaction; and highlighting gaps in the current evidence to guide future research.

Methods

This systematic review was conducted and reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines⁽⁶⁾.

Search strategy

A comprehensive electronic search was performed in PubMed/MEDLINE, Web of Science, Scopus, Embase, BVS/LILACS, The Cochrane Library, and PsycINFO to identify studies reporting surgical outcomes of arthrodesis and alternative surgical techniques for hallux rigidus. The search strategy combined Medical Subject Headings (MeSH) terms and free-text keywords related to hallux rigidus and surgical management, including: “hallux rigidus,” “first metatarsophalangeal joint,” “arthrodesis,” “interpositional arthroplasty,” “implant arthroplasty,” and “motion-preserving procedures.” The complete search strategy for each database is detailed in Table 1.

Study selection

Two independent reviewers screened titles and abstracts for eligibility. Full-text articles were subsequently assessed to confirm inclusion. Disagreements were resolved by consensus. Studies were included if they reported clinical outcomes of surgical treatment for hallux rigidus. Comparative and non-comparative clinical studies were eligible for inclusion.

Case reports and small case series were excluded from comparative analysis due to their inherent methodological limitations and high risk of bias. These studies were not considered in outcome synthesis.

Eligibility criteria

Studies were included if they met the following criteria: (1) adult patients diagnosed with hallux rigidus; (2) surgical treatment involving arthrodesis or motion-preserving techniques; and (3) reporting of clinical outcomes, complications, or revision rates. Studies focusing exclusively on non-surgical management or biomechanical analyses without clinical outcomes were excluded.

Time frame and rationale

The search period covered publications from 2020 to 2025, reflecting the rapid evolution in motion-preserving surgical techniques and implant designs during this period, and building upon previously published systematic reviews that covered earlier literature^(4,5). Studies published before 2020

Table 1. Database search strategies

Database	Search strategies
Web of Science	(“hallux rigidus”) AND (arthrodesis OR “joint fusion”) AND (arthroplasty OR “joint replacement” OR “resection arthroplasty”) AND (surgery OR “surgical treatment” OR “operative technique”)
PubMed/MEDLINE	(“Hallux Rigidus”[MeSH Terms] OR “Hallux Rigidus” OR “Stiff big toe”) AND (“Arthrodesis”[MeSH Terms] OR “Arthrodesis” OR “Joint Fusion”) AND (“Arthroplasty”[MeSH Terms] OR “Arthroplasty” OR “Joint Replacement”) AND (“Surgical Procedures, Operative”[MeSH Terms] OR “Surgical Treatment”)
BVS/Lilacs	(“hallux rigidus” OR “hallux rígido” OR “hallux rígrado” OR “rigidez do hálux” OR “rigidez metatarsofalângica” OR “hallux limitus”) AND (“artrodese” OR “arthrodesis” OR “artrodesis” OR “fusão articular” OR “fusão óssea”) AND (“artroplastia” OR “arthroplasty” OR “artroplastia” OR “substituição articular” OR “reposição articular”) AND (“tratamento cirúrgico” OR “surgical treatment” OR “tratamiento quirúrgico” OR “cirurgia ortopédica” OR “procedimento cirúrgico”)
Scopus	(TITLE-ABS-KEY (“hallux rigidus”) AND TITLE-ABSKEY (“arthrodesis”) AND TITLE-ABS-KEY (“arthroplasty” OR “joint replacement” OR “resection arthroplasty”) AND TITLE-ABS-KEY (“surgical treatment” OR “operative technique” OR “surgery”))
EMBASE	(‘hallux rigidus’/exp OR ‘hallux rigidus’:ti,ab) AND (‘arthrodesis’/exp OR arthrodesis:ti,ab OR ‘joint fusion’:ti,ab) AND (‘arthroplasty’/exp OR arthroplasty:ti,ab OR ‘joint replacement’:ti,ab OR ‘resection arthroplasty’:ti,ab) AND (‘surgical procedure’/exp OR ‘surgical treatment’:ti,ab OR surgery:ti,ab)
psychINFO	((MH “Hallux Rigidus” OR TI “Hallux Rigidus” OR AB “Hallux Rigidus”) AND (MH “Arthrodesis” OR TI Arthrodesis OR AB Arthrodesis OR TI “Joint Fusion” OR AB “Joint Fusion”) AND (MH “Arthroplasty” OR TI Arthroplasty OR AB Arthroplasty OR TI “Joint Replacement” OR AB “Joint Replacement”) AND (MH “Surgical Procedures, Operative” OR TI “Surgical Treatment” OR AB “Surgical Treatment”))
The Cochrane Library	(“hallux rigidus”) AND (arthrodesis OR “joint fusion”) AND (arthroplasty OR “joint replacement” OR “resection arthroplasty”) AND (“surgical treatment” OR surgery OR “operative technique”)

reporting exclusively on established techniques without novel comparators were considered beyond the scope of this update.

Data extraction

Data extraction was performed independently by two reviewers using a standardized form. Extracted variables included study design, sample size, surgical technique, outcome measures, follow-up duration, and reported complications.

Risk of bias and quality assessment

Given the predominance of non-randomized studies, methodological quality was assessed using appropriate tools for observational research. The risk of bias was considered when interpreting the results⁽⁷⁾.

Data synthesis

Due to substantial heterogeneity among studies regarding surgical techniques, outcome measures, and follow-up periods, a meta-analysis was not performed. Instead, a qualitative synthesis of the available evidence was conducted, focusing on reported outcomes and complication profiles.

Results

Study selection

The database search yielded 774 records. After duplicate removal, 122 unique records were screened by title and abstract. Following a full-text assessment of 25 articles, 15 studies met the eligibility criteria and were included in the qualitative synthesis. The study selection process is summarized in the PRISMA flow diagram (Figure 1).

Study characteristics

The included studies were predominantly observational, with retrospective cohort designs comprising most available evidence. Sample sizes varied across studies, and follow-up durations ranged from short- to mid-term. Both arthrodesis and motion-preserving techniques were represented, including interpositional arthroplasty, implant arthroplasty, and other joint-preserving procedures (Tables 2 and 3, Figure 2).

Surgical techniques

Arthrodesis techniques included various fixation methods and joint preparation strategies. Motion-preserving procedures encompassed a range of surgical approaches, with heterogeneity in materials, interposition techniques, and implant designs reported across studies.

Outcome measures

A wide variety of outcome measures were reported, including patient-reported outcome scores, pain assessment scales, range of motion measurements, and functional eva-

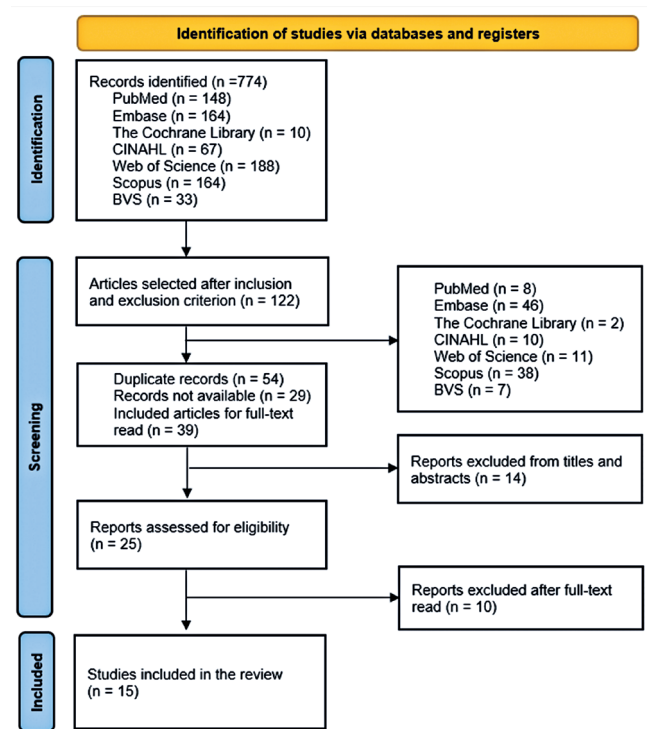


Figure 1. Screening and selection of studies according to the PRISMA methodology.

uations (Table 4 and Figure 3). The instruments used were not standardized across studies, limiting direct comparability.

Complications and reoperations

Reported complications included nonunion, hardware-related issues, persistent pain, implant failure, and the need for revision surgery. The type and frequency of complications varied across surgical techniques and study designs. Reoperation rates were reported inconsistently across studies.

Comparative data

Direct comparative studies between arthrodesis and motion-preserving techniques were limited. When present, comparative analyses were based on heterogeneous outcome measures and differing follow-up durations. No pooled quantitative analysis was performed.

Discussion

The present systematic review provides a qualitative synthesis of the available literature on surgical management of hallux rigidus, focusing on outcomes and complication profiles of arthrodesis and motion-preserving techniques. The main finding of this review is the substantial heterogeneity of the current evidence, which limits direct comparison between surgical procedures.

Table 2. Synthesis of the characteristics and main results of the included studies

Number	Title	Author/year	Objective	Results	Results
1	Minimally-invasive hallux arthrodesis with endomedullary and a crossed screw fixation.	Carlucci et al., 2020	Describe the minimally invasive arthrodesis technique and evaluate its initial results.	Consolidation rate of 93.3%. Score improved from 49 to 90. There was 1 superficial infection and 1 case of asymptomatic pseudoarthrosis.	Minimally invasive arthrodesis was safe and presented results comparable to open approaches.
2	Gait and dynamic pedobarographic analyses in hallux rigidus patients treated with Keller's arthroplasty, arthrodesis or cheilectomy 22 years after surgery.	Bot et al., 2023	To assess the long-term (22 years) effects of different surgeries on gait, plantar pressure, and clinical outcome.	Gait parameters and plantar pressure were similar between all groups.	In the long term, there was no functional or biomechanical superiority between the surgical techniques evaluated.
3	Achieving high union rates after first metatarsophalangeal joint arthrodesis: Radiographic outcomes and technical pitfalls.	Von Deimling et al., 2023	To evaluate the results of a specific arthrodesis technique.	Consolidation rate of 98.6%. Only 1 case of pseudoarthrosis, attributed to the patient's non-adherence to the postoperative period. There was no correlation between the degree of correction and the risk of pseudoarthrosis.	The technique has achieved consolidation rates close to 100%, even in high-risk patients.
4	Conversion of First Metatarsal-Phalangeal Joint Arthrodesis to Arthroplasty: A Case Report.	Walsh et al., 2023	To present a case of conversion from arthrodesis to arthroplasty.	Patient dissatisfied with the limitations of arthrodesis obtained "fantastic satisfaction" after conversion.	Conversion may be a rescue option for selected patients who do not adapt to joint fusion.
5	A Comparison of PROMIS Scores of Metatarsophalangeal Joint Arthrodesis and Polyvinyl Alcohol Hydrogel Implant Hemiarthroplasty for Hallux Rigidus.	El Masry et al., 2024	To compare outcomes between arthrodesis and hemiarthroplasty.	The outcome scores were similar, except for pain intensity, which was significantly lower in the arthrodesis group.	Arthrodesis was more effective at reducing pain than hydrogel hemiarthroplasty.
6	Better results in consolidation of hallux metatarsophalangeal arthrodesis with dorsal plate and interfragmentary compression screw.	García-Jarabo et al., 2024	To analyze whether the addition of an interfragmentary compression screw to the dorsal plate improves consolidation outcomes.	Significantly higher consolidation rate in the screw group.	The use of a compression screw with the dorsal plate improved consolidation results.
7	Arthrodesis using Iliac Crest autograft in revision surgery of the first metatarsophalangeal joint total arthroplasty for the treatment of Hallux Rigidus: a retrospective study.	Yurteri et al., 2024	To evaluate revision arthrodesis after total arthroplasty failure.	Significant improvement in outcome scores and 100% consolidation rate.	Revision arthrodesis with a graft was safe and effective for treating the failure of total arthroplasties.
8	Primary Isolated Arthrodesis of the First Metatarsophalangeal Joint for Hallux Rigidus: Clinical, Radiologic, and Pedobarographic Evaluation.	Fragnière et al., 2024	Evaluate the results of an arthrodesis technique.	Consolidation in 100% of cases. High patient satisfaction.	The technique was safe and effective for the treatment of advanced hallux rigidus.
9	Cartiva interpositional arthroplasty versus arthrodesis in the treatment of Hallux rigidus: A retrospective comparative study with mean 2 year follow up	Lewis et al., 2024	To compare clinical outcomes of Cartiva versus arthrodesis.	No significant difference in scores. The reoperation rate was 29.4% in the Cartiva group and 0% in the arthrodesis group.	Arthrodesis demonstrated a significantly lower reoperation rate (0% vs. 29.4%), supporting its use in patients for whom revision surgery is a major concern.
10	Synthetic cartilage implant vs. first metatarsophalangeal arthrodesis for the treatment of hallux rigidus.	Budde et al., 2024	Compare the synthetic cartilage implant with arthrodesis.	No functional differences, but significantly lower pain on exertion in the arthrodesis group.	Arthrodesis showed lower residual pain on exertion and lower revision rates compared with the synthetic cartilage implant.
11	Polyvinyl Alcohol Hydrogel Hemiarthroplasty of First Metatarsophalangeal Joint Hallux Rigidus.	Anastasio et al., 2024	To report the five-year experience with hydrogel implants (Cartiva).	Improvement in pain and dorsiflexion. Revision rate: 12.3%. Complication rate: 15.1%.	The technique improved pain and function but was associated with a considerable rate of revisions and complications.

continue...

...Continuation

Table 2. Synthesis of the characteristics and main results of the included studies

Number	Title	Author/ year	Objective	Results	Results
12	Ten-Year Minimum Follow-up Study of First Metatarsophalangeal Joint Fusion in Young vs Old Patients.	Scheurer et al., 2024	To compare long-term outcomes of arthrodesis in young and old.	Significantly greater pain relief in young patients. No difference in functional results.	Arthrodesis is a valid and highly satisfactory option for the treatment of hallux rigidus, even in young patients, with long-lasting results.
13	Fifteen-Year Follow-up of the Modified Oblique Keller Capsular Interposition Arthroplasty Compared to Arthrodesis for Treatment of Advanced First Metatarsophalangeal Joint Arthritis.	Johnson et al., 2025	To compare the long-term outcomes of interposition arthroplasty (MOKCIA) with arthrodesis.	High function in both groups. The MOKCIA group had slightly lower pain scores and higher satisfaction.	Interposition arthroplasty (MOKCIA) demonstrated motion preservation with comparable functional outcomes to arthrodesis at 15-year follow-up.
14	Short-Term Outcomes of First Metatarsophalangeal Arthroplasty Using the Silktoe Double-Stemmed Silicone Implant.	Fieschi; Redaelli; Fazzini, 2025	To evaluate short-term outcomes of a silicone implant.	Excellent score results. No complications, revisions, or reoperations in two years.	The implant showed excellent short-term results, but requires longer follow-up.
15	Treatment of Hallux Rigidus: Comparison of Hemiarthroplasty with Cartiva Implant, Allograft Interpositional Arthroplasty, and Arthrodesis.	Sanii et al., 2025	Compare three surgical techniques.	The improvement in scores was significantly greater in the Arthrodesis and Interposition groups.	Arthrodesis and interposition arthroplasty with allograft showed significantly greater improvements in outcome scores than hemiarthroplasty with the Cartiva implant.

Table 3. Design and level of evidence of included studies

Number	Study design/sample	Follow-up time	L.E.
1	Retrospective study; 15 feet.	Minimum of 1 year	4
2	Long-term follow-up study; 27 patients.	22 years	2
3	Retrospective study; 72 MTP1 mergers.	3 to 18 months	4
4	Case report; a 70-year-old patient.	Not specified	5
5	Retrospective study; 82 hemiarthroplasties, 101 arthrodesis.	Minimum of 1 year	3
6	Retrospective cohort; 55 cases.	Mean of 26 months	3
7	Retrospective study; 27 patients.	Minimum of 6 months	4
8	Prospective study; 13 patients.	Mean of 26 months	4
9	Retrospective cohort; 33 cases.	2-year medium	3
10	Retrospective paired case-control; 36 patients.	Mean of 2.5 years	3
11	Case series; 146 procedures.	Mean of 5 years	4
12	Retrospective cohort; 61 mergers.	Minimum of 10 years	3
13	Retrospective cohort; 35 patients.	15 years	3
14	Retrospective study; 37 patients.	2 years	4
15	Retrospective cohort; 99 patients.	Minimum of 2 years	3

Most included studies were retrospective, with variations in patient selection, disease severity, surgical technique, outcome measures, and follow-up duration. These methodological differences introduce significant risk of bias and reduce the ability to draw definitive comparative conclusions. Similar limitations have been highlighted in previously published systematic reviews addressing surgical treatment of hallux rigidus, which consistently report low-quality evidence and a lack of high-quality randomized controlled trials^(4,5).

Arthrodesis of the first metatarsophalangeal joint is widely regarded in the literature as a reliable procedure for pain relief in advanced hallux rigidus, as reflected by its frequent

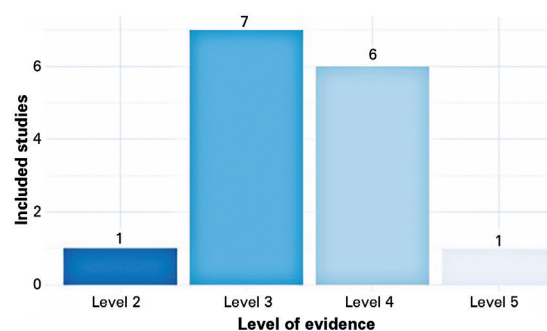
**Figure 2.** Distribution of included studies by level of evidence.

Table 4. Summary of key outcomes by type of intervention

Outcome	Arthrodesis MTPI	Arthroplasty with synthetic implant (Cartiva)	Interposition arthroplasty (MOKCIA)
Pain relief (General)	Excellent and consistent. Superior to synthetic implants in several studies.	Significant improvement, but often less than arthrodesis in residual pain or on exertion.	Excellent, with motion preservation and comparable long-term functional outcomes.
Reoperation rate	Very Low (0% to 7%)	High (12.3% to 29.4%)	Very Low (0% in the included study)
Main complications	Pseudoarthrosis (rare with modern techniques). Material removal.	Implant subsidence, erosive bone changes, and mechanical failure.	(Not significantly reported in the included studies).
Patient satisfaction	High (driven by pain relief).	Variable, often less than arthrodesis due to residual pain or failure.	Very High (driven by preservation of movement and pain relief).
Motion preservation	No (motion is eliminated)	Yes (main objective)	Yes (main objective)

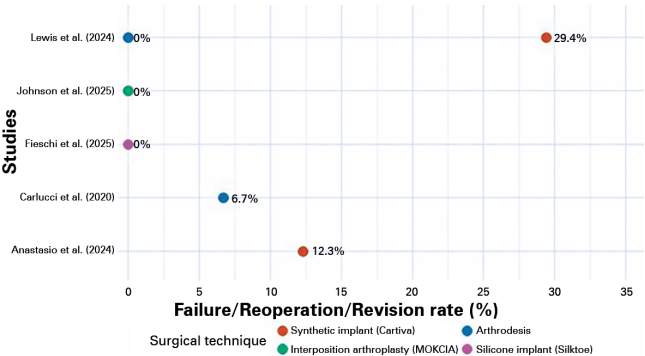


Figure 3. Comparison of failure, reoperation, or revision rates among different surgical techniques.

use as a reference technique in clinical studies⁽⁸⁻¹⁴⁾. In contrast, motion-preserving procedures have been described using diverse surgical approaches and materials, resulting in a broad spectrum of reported outcomes⁽¹⁵⁻²¹⁾. The variability in indications and techniques further complicates meaningful comparison.

Several prior systematic reviews have emphasized that the existing literature does not provide sufficient comparative data to establish superiority or equivalence among surgical techniques. The findings of the present review are consistent with these observations, reinforcing the notion that current evidence remains limited by study design and heterogeneity^(4,5).

The present findings are consistent with those of de Bot et al.^(4,5), who similarly reported that arthrodesis yields reliable pain relief and functional restoration but is associated with permanent loss of motion, whereas hemiarthroplasty preserves motion at the cost of higher revision rates. Com-

parable limitations regarding study heterogeneity and the absence of high-quality randomized controlled trials have been consistently reported in previously published systematic reviews addressing hallux rigidus, reinforcing the conclusion that robust comparative evidence remains scarce in this field^(4,5). The findings of the current review align with these observations and further emphasize that definitive comparative conclusions cannot be drawn from the currently available literature.

This review has important limitations. The absence of randomized controlled trials, inconsistent reporting of outcomes, and the predominance of observational studies limit the strength of the conclusions. Additionally, the inability to perform a meta-analysis due to heterogeneity further underscores the descriptive nature of the findings. These factors should be carefully considered when interpreting the results⁽⁷⁾.

Future research should prioritize well-designed comparative studies with standardized outcome measures and adequate follow-up to better define the role of motion-preserving techniques in relation to arthrodesis. Until such data are available, surgical decision-making should be individualized, considering patient characteristics, disease stage, and surgeon experience⁽²²⁾.

Conclusion

Based on the current literature, definitive conclusions regarding the superiority or equivalence of arthrodesis and motion-preserving surgical techniques for hallux rigidus cannot be established. The available evidence is characterized by heterogeneity, methodological limitations, and predominance of low-level studies. Arthrodesis remains a well-established reference procedure, while the role of alternative techniques requires further clarification through high-quality comparative research.

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Systematic Review

Association between fluoroquinolones and Achilles tendon injuries: A systematic review

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Abstract

Objective: To analyze the available scientific evidence on the association between fluoroquinolone use and the risk of Achilles tendon injuries, including tendinopathy, tendinitis, and tendon rupture, compared with unexposed individuals or those exposed to other antibiotics.

Methods: A systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations. Searches were performed in MEDLINE via PubMed, Embase, the Cochrane Library, SciELO, and Google Scholar as a supplementary search source. Study selection, data extraction, and methodological quality assessment were performed by two independent reviewers using Joanna Briggs Institute tools according to each study design.

Results: Seventeen studies were included, predominantly cohort studies, case-control studies, and case reports, with higher methodological quality among studies with a comparator group. The evidence indicated an association between fluoroquinolones and an increased risk of tendinitis, tendinopathy, and Achilles tendon rupture, particularly during the first weeks after exposure. Risk was higher among older adults, patients with renal impairment, diabetes mellitus, obesity, and corticosteroid users. Ciprofloxacin and levofloxacin were the drugs most frequently associated with tendon outcomes.

Conclusion: Fluoroquinolones are associated with an increased risk of Achilles tendon injuries, particularly among individuals with predisposing factors. Early identification of at-risk groups and judicious prescribing of these antimicrobials may reduce severe tendon complications.

Level of evidence V; Systematic Review.

Keywords: Achilles tendon; Fluoroquinolones; Tendon rupture; Tendinopathy; Antibiotic therapy.

Introduction

Fluoroquinolones are a class of broad-spectrum antibiotics used to treat urinary, respiratory, gastrointestinal, and osteo-articular infections due to their high oral bioavailability, good tissue penetration, and prolonged half-life^(1,2). However, their widespread clinical use has been associated with relevant musculoskeletal adverse events^(3,4).

Among these events, tendon injuries, including tendinitis, tendinopathy, and tendon rupture, are particularly noteworthy⁽⁵⁾. The Achilles tendon is the main site affected,

possibly because of high biomechanical loading and reduced local vascularity, factors that favor degenerative changes following drug exposure^(6,7). Risk is higher among older adults, patients with renal impairment or diabetes mellitus, corticosteroid users, and individuals exposed to greater mechanical demand on the tendons⁽⁸⁾.

Although the pathophysiology has not yet been fully elucidated, evidence suggests that fluoroquinolones may induce collagen degradation, oxidative stress, and extracellular matrix alterations, thereby compromising tendon strength⁽⁹⁾.

Study performed at the Universidade José do Rosário Vellano, Faculdade de Medicina, Alfenas, MG, Brazil.

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Clinically, these changes may cause pain, edema, stiffness, and functional limitation and may progress to partial or complete tendon rupture, a condition associated with functional impairment and a possible need for surgical treatment⁽¹⁰⁾.

The clinical relevance of this association has prompted warnings from international regulatory agencies, such as the Food and Drug Administration (FDA) and the European Medicines Agency (EMA), regarding the risk of tendinitis and tendon rupture associated with fluoroquinolones^(11,12). Nevertheless, these antibiotics remain widely prescribed, including settings in which therapeutic alternatives are available⁽¹³⁾.

Despite the growing scientific literature on this topic, the available evidence remains characterized by a predominance of observational studies, case reports, and reviews, with heterogeneity in the populations, fluoroquinolones investigated, and diagnostic criteria for tendon outcomes^(14,15). These limitations hinder precise estimation of the magnitude of risk and the definition of preventive strategies^(16,17).

A previous systematic review and meta-analysis addressed this association⁽¹³⁾; however, more recent primary studies have evaluated large population-based samples, active antibiotic comparators, and pharmacovigilance data. An updated synthesis is therefore warranted. Accordingly, this study aimed to analyze the available scientific evidence on the association between fluoroquinolone use and the risk of Achilles tendon injuries, including tendinopathy, tendinitis, and tendon rupture.

Methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) recommendations⁽¹⁸⁾, and its protocol was registered in PROSPERO under number CRD420261414571⁽¹⁹⁾.

Research question

The guiding question was structured according to the PECO framework (Population, Exposure, Comparator, and Outcome)⁽²⁰⁾, as follows: population, individuals exposed to fluoroquinolones; exposure, use of ciprofloxacin, levofloxacin, moxifloxacin, norfloxacin, or ofloxacin; comparator, unexposed individuals or users of other antibiotics; and outcome, Achilles tendon injuries, including tendinopathy, tendinitis, and tendon rupture.

Eligibility criteria

Primary observational studies, including cohort, case-control, cross-sectional, and pharmacovigilance studies, as well as randomized clinical trials, case series, and case reports, published in English, Portuguese, or Spanish between 2017 and 2026, were eligible. Studies were included when they assessed Achilles tendon injuries, including tendinopathy, tendinitis, or tendon rupture, following exposure to fluoro-

quinolones. Comparative studies were required to include individuals unexposed to fluoroquinolones or exposed to other antibiotics as comparators. *In vitro* and animal studies, opinion articles, editorials, letters without original empirical data, narrative reviews, systematic reviews, meta-analyses, scoping reviews, and studies that did not directly assess the association of interest were excluded.

Search strategies

The search was performed on July 12, 2026, in the following electronic databases and information sources: Scientific Electronic Library Online (SciELO), Medical Literature Analysis and Retrieval System Online (MEDLINE) via PubMed, Excerpta Medica database (Embase), the Cochrane Library, and Google Scholar as a supplementary search source. Controlled vocabulary and free-text terms were selected according to each database. Medical Subject Headings (MeSH) were used in PubMed and the Cochrane Library, Emtree terms in Embase, and Health Sciences Descriptors (DeCS) in SciELO. In Google Scholar, combinations of free-text terms were used. The Boolean operators “OR” and “AND” were used to combine controlled terms and alternative keywords, as shown in Table 1.

Study selection

Study selection was performed by two independent reviewers. Initially, records identified in the databases were exported to Rayyan® software⁽²¹⁾, where duplicates were removed, titles and abstracts were screened, and potentially eligible studies were assessed in full text. Disagreements were resolved by consensus.

Data extraction

Data extraction was performed using a previously developed instrument applied independently by the reviewers. Information on study methodological characteristics was collected, including authors, year of publication, country, study design, population assessed, type of fluoroquinolone used, comparator group, outcomes, and main findings. Data were organized in Microsoft Excel® spreadsheets and presented descriptively in figures and tables. For comparative studies, the reported effect measures were also extracted, including odds ratios, incidence rate ratios, hazard ratios, risk ratios, absolute rate differences, and their respective 95% confidence intervals, when available.

Methodological quality assessment

Methodological quality was assessed using the Joanna Briggs Institute (JBI) critical appraisal tools⁽²²⁾, according to each study design. Aspects related to participant selection, exposure definition, outcome measurement, control of confounders, and appropriateness of the analyses were considered.

Table 1. Search strategies used in the databases consulted for the systematic review

Database	Search strategy
PubMed*/MEDLINE	((("Fluoroquinolones"[Mesh] OR fluoroquinolone*[tiab] OR quinolone*[tiab] OR ciprofloxacin[tiab] OR levofloxacin[tiab] OR moxifloxacin[tiab] OR norfloxacin[tiab] OR ofloxacin[tiab])) AND ((("Achilles Tendon"[Mesh] OR "Tendon Injuries"[Mesh] OR "Tendinopathy"[Mesh] OR achilles tendon[tiab] OR achilles tendinopathy[tiab] OR achilles tendinitis[tiab] OR tendon rupture[tiab] OR tendinopathy[tiab] OR tendinitis[tiab] OR tendon injur*[tiab]))) AND ((("Drug-Related Side Effects and Adverse Reactions"[Mesh] OR adverse effect*[tiab] OR side effect*[tiab] OR drug-induced[tiab] OR risk[tiab] OR association[tiab]))).
Embase* (EMTREE)	('fluoroquinolone'/exp OR fluoroquinolone*:ti,ab OR quinolone*:ti,ab OR ciprofloxacin:ti,ab OR levofloxacin:ti,ab OR moxifloxacin:ti,ab OR norfloxacin:ti,ab OR ofloxacin:ti,ab) AND ('achilles tendon'/exp OR 'tendon injury'/exp OR tendinopathy/exp OR 'achilles tendon':ti,ab OR 'tendon rupture':ti,ab OR tendinopathy:ti,ab OR tendinitis:ti,ab) AND ('adverse drug reaction'/exp OR risk:ti,ab OR association:ti,ab OR 'drug induced':ti,ab).
Cochrane Library	(fluoroquinolone* OR quinolone* OR ciprofloxacin OR levofloxacin OR moxifloxacin) AND ("Achilles tendon" OR tendinopathy OR tendinitis OR "tendon rupture")
SciELO	(fluoroquinolones OR quinolones) AND ("Achilles tendon" OR tendinopathy OR tendinitis OR tendon rupture).
Google Scholar	"fluoroquinolones" AND ("Achilles tendon" OR tendinopathy OR tendinitis OR "tendon rupture")

Data synthesis

The search strategy and article inclusion process were documented using the PRISMA flow diagram⁽¹⁸⁾. The data obtained were consolidated into tabular matrices and analyzed descriptively. Owing to the clinical and methodological heterogeneity among the included studies, statistical pooling was not considered appropriate. Therefore, the findings were synthesized narratively, and the effect estimates of the comparative studies were presented in tabular form according to the tendon outcome and type of fluoroquinolone exposure.

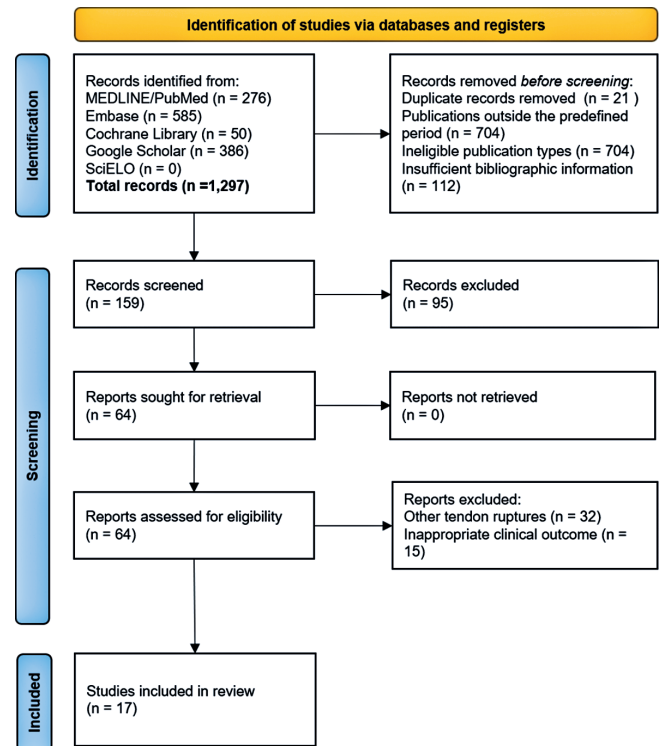
Results

A total of 1,297 records were identified in MEDLINE/PubMed, Embase, the Cochrane Library, Google Scholar, and SciELO. Twenty-one duplicate records and 1,117 records were removed before screening. A total of 159 records remained for screening in Rayyan®. Subsequently, 95 records were excluded after title and abstract screening. Of the 64 reports assessed for eligibility, 47 were excluded because they did not meet the established criteria, resulting in 17 studies included in the final synthesis, as shown in the PRISMA flow diagram in Figure 1⁽¹⁸⁾.

General characteristics of the studies included in the systematic review

Seventeen studies were included; publications from North America accounted for 47.0% (n = 8) of the sample, followed by Europe with 29.4% (n = 5) and Asia with 23.5% (n = 4). The United States had the highest number of publications, representing 41.1% (n = 7), followed by the United Kingdom with 17.6% (n = 3). Canada, Ireland, Denmark, India, China, Taiwan, and Japan each accounted for 5.9% (n = 1) of the included studies.

Regarding methodological design, cohort studies predominated, accounting for 47.1% (n = 8) of the sample, followed

**Figure 1.** PRISMA 2020 flow diagram of the study selection process for the systematic review.

by case reports with 23.5% (n = 4), case-control studies with 11.8% (n = 2), and one case series, one descriptive observational study, and one pharmacovigilance analysis, each accounting for 5.9% (n = 1). Levofloxacin was the most frequently assessed fluoroquinolone, appearing in 76.5% (n = 13) of the studies, followed by ciprofloxacin in 58.8% (n = 10) and moxifloxacin in 47.1% (n = 8). Eleven studies (64.7%) included a comparator group, generally individuals

unexposed to fluoroquinolones, users of non-fluoroquinolone antibiotics, or other reports in pharmacovigilance databases. Six studies (35.3%) had no formal comparator group, including case reports, a case series, and a descriptive analysis of incident and compensation records (Table 2).

Methodological quality and risk-of-bias assessment

The methodological quality and risk of bias of the 17 included studies were assessed using the JBI critical appraisal tools⁽²²⁾, with the checklist corresponding to each study

Table 2. General characteristics of the studies included in the systematic review

Author/Year	Country	Population	Sample	Study design	Type of fluoroquinolone	Comparator group	JBI Appraisal results
Morales et al. (2019)	United Kingdom	Adults aged ≥18 years from the THIN primary care database exposed to systemic fluoroquinolones or co-amoxiclav	4,836 cases and 18,356 matched controls (source cohort: 1,351,780 adults)	Case-control study	Systemic fluoroquinolones: ciprofloxacin, moxifloxacin, levofloxacin, norfloxacin, and ofloxacin	Matched controls selected from the source cohort prescribed systemic fluoroquinolone or co-amoxiclav; co-amoxiclav was also used as an active negative comparator	JBI Case control checklist/ Low risk of bias
Persson and Jick (2019)	United Kingdom	Patients from the CPRD Gold database	3,802 cases / 14,002 controls	Case-control study	Fluoroquinolones	Matched controls	JBI Cohort study checklist/ Low risk of bias
Baik et al. (2020)	United States	Medicare fee-for-service beneficiaries aged ≥65 years enrolled under the federal Old-Age and Survivors Insurance program	1,009,925 participant	Case-control study	Oral fluoroquinolones: ciprofloxacin, levofloxacin, and moxifloxacin	No exposure to the respective fluoroquinolone; non-fluoroquinolone antibiotics: amoxicillin, amoxicillin-clavulanate, azithromycin, and cephalexin	JBI Case-control checklist/ Low risk of bias
Rasmus et al. (2024)	Denmark	General population registered in national health databases	Nationwide	Case-control study	Oral fluoroquinolones	Amoxicillin	JBI Case-control checklist/ Low risk of bias
McCullagh et al. (2025)	Ireland	Patients exposed to fluoroquinolones with tendon injury records reported to the national incident and compensation system	20 incidents and 4 compensation claims related to tendon injury	Retrospective cohort study	Ciprofloxacin and levofloxacin	Not applicable	JBI Retrospective cohort study checklist/ Low risk of bias
Zellers et al. (2024)	United States	Patient with bilateral Achilles tendon rupture associated with fluoroquinolone use	One patient	Case report	Levofloxacin	Not applicable	JBI Case report checklist/ Moderate risk of bias
Tran et al. (2023)	United States	Patients treated with quinolone-containing otic drops	Retrospective cohort based on an administrative database	Cohort study	Otic quinolones (ofloxacin and ciprofloxacin)	Otic neomycin, oral amoxicillin, or azithromycin	JBI Cohort study checklist/ Low risk of bias
Shu et al. (2022)	China	Reports of fluoroquinolone-related adverse events recorded in US FAERS between 2016 and 2021	35,667 adverse events associated with fluoroquinolones, including 1,771 cases of tendinitis and 1,018 tendon ruptures	Descriptive and analytical observational study of the pharmacovigilance type	Ciprofloxacin, levofloxacin, and moxifloxacin	Comparison among different fluoroquinolones and other reports in the FAERS database	JBI Descriptive and analytical observational checklist/ Low risk of bias

continue...

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Table 2. General characteristics of the studies included in the systematic review

Author/Year	Country	Population	Sample	Study design	Type of fluoroquinolone	Comparator group	JB1 Appraisal results
Fleming et al. (2024)	United States	Adult patients treated for community-acquired pneumonia (CAP)	436,257 patients from the combined MarketScan CCAE and COB databases	Retrospective cohort study	Ciprofloxacin, levofloxacin, and moxifloxacin	Amoxicillin-clavulanate, azithromycin, doxycycline, among others	JB1 Retrospective cohort study checklist/ Low risk of bias
Fleming et al. (2025)	United States	Adult patients with urinary tract infection (UTI) and no previous history of tendon injury	2,234,036 patients identified in the MarketScan® databases between 2014 and 2020	Retrospective cohort study	Ciprofloxacin, levofloxacin, and moxifloxacin	Nitrofurantoin, sulfamethoxazole/trimethoprim, cephalaxin, amoxicillin-clavulanate, amoxicillin, azithromycin, doxycycline, cefdinir, and cefuroxime	JB1 Retrospective cohort study checklist/ Low risk of bias
Gupta and Katiyar (2020)	India	Incidence of tendinopathies in adult patients treated with fluoroquinolones at an orthopedic clinic	108 participants (54 fluoroquinolone-associated tendinopathy cases and 54 matched controls without tendinopathy)	Case-control study	Ciprofloxacin, levofloxacin, ofloxacin, and moxifloxacin	Controls without fluoroquinolone-associated tendinopathy (ofloxacin and moxifloxacin)	JB1 Case-control checklist/ Low risk of bias
Alison (2024)	United Kingdom	Patients with Achilles tendon rupture associated with fluoroquinolone use	Case series of 13 patients with Achilles tendon rupture	Case report	Not reported in the study	Not applicable	JB1 Case report checklist/ Moderate risk of bias
Chang et al. (2022)	Taiwan	Individuals registered in the National Health Insurance Research Database (NHIRD) between 2000 and 2015	714,140 individuals: 357,070 fluoroquinolone-exposed participants and 357,070 matched unexposed controls	Cohort study	Ciprofloxacin, levofloxacin, norfloxacin, ofloxacin, gemifloxacin, and moxifloxacin	Individuals not exposed to fluoroquinolones	JB1 Cohort study checklist/ Low risk of bias
Anziano (2024)	Canada	Older woman with Achilles tendinitis after exposure to a fluoroquinolone	One patient	Case report	Levofloxacin	Not applicable	JB1 Case report checklist/ Moderate risk of bias
Kaneko et al. (2024)	Japan	Patient with autosomal dominant polycystic kidney disease undergoing treatment for hepatic cyst infection	One patient	Case report	Levofloxacin	Not applicable	JB1 Case report checklist/ Moderate risk of bias
Anderson et al. (2025)	United States	Patient with bilateral Achilles tendon rupture after levofloxacin use	One patient	Case report	Levofloxacin	Not applicable	JB1 Case report checklist/ Moderate risk of bias
Patel et al. (2024)	United States	Patients hospitalized with community-acquired pneumonia	1,071 patients	Retrospective cohort study	Moxifloxacin, levofloxacin, and ciprofloxacin	Aminoglycosides, carbapenems, cephalosporins, clindamycin, linezolid, macrolides, metronidazole, penicillins, tetracyclines, TMP/SMX, and vancomycin	JB1 Retrospective cohort study checklist/ Low risk of bias

Abbreviations: FDA: Food and Drug Administration; FAERS: FDA Adverse Event Reporting System; CAP: Community-acquired pneumonia; UTI: Urinary tract infection; CCAE: Commercial Claims and Encounters; COB: Coordination of Benefits; NHIRD: National Health Insurance Research Database; TMP: Trimethoprim; SMX: Sulfamethoxazole; JB1: Joanna Briggs Institute.

design. Criteria related to participant selection, definition of fluoroquinolone exposure, measurement of tendon outcomes, control of confounding factors, and appropriateness of statistical analyses were considered.

Overall, cohort and case-control studies had higher methodological quality and a lower risk of bias because they included comparator groups and adjustment for confounding factors. Case reports and case series had a higher risk of bias because of the absence of a comparator group and their limited capacity for causal inference, although they contributed to the clinical and temporal description of fluoroquinolone-associated tendon injuries (Table 2).

Clinical outcomes and association between fluoroquinolones and Achilles tendon injuries

The main outcomes assessed were tendinitis, tendinopathy, and Achilles tendon rupture. Most studies identified an association between fluoroquinolone exposure and the occurrence of tendon events, particularly during the first weeks after use. Risk was most frequently associated with advanced age, concomitant corticosteroid use, renal impairment, diabetes mellitus, obesity, and greater mechanical demand on the tendons.

Comparative studies reported heterogeneous effect measures, including odds ratios, incidence rate ratios, hazard ratios, reporting odds ratios, and absolute rate differences. Despite differences in study design, exposure windows, and comparator groups, most estimates indicated an increased risk of Achilles tendon injury following fluoroquinolone exposure. The effect estimates reported by the comparative studies are summarized in Table 3.

Discussion

The results of this review are consistent with an association between fluoroquinolone exposure and tendon injuries, particularly those involving the Achilles tendon. This association was observed across different study designs, including case-control studies, population-based cohorts, pharmacovigilance analyses, and studies conducted in specific clinical populations. Studies with a comparator group identified a higher risk of tendinitis, tendinopathy, and tendon rupture among individuals exposed to fluoroquinolones than among unexposed individuals or users of non-fluoroquinolone antibiotics, strengthening the epidemiological plausibility of this relationship^(23,29-31,34). Even in settings with a low absolute frequency, studies in hospitalized populations identified tendinitis as a clinically relevant adverse event, with functional and care-related implications that justify clinical monitoring⁽³⁸⁾.

A recurring finding was the concentration of events in the period immediately following drug exposure. The included studies indicated a higher risk during the first weeks after treatment initiation, particularly within the first 30 days, with attenuation of the association over longer follow-up periods^(23,29-31). This temporal pattern suggests a window of

greater clinical vulnerability during which monitoring for pain, edema, stiffness, or functional limitation of the Achilles tendon should be intensified.

The occurrence of injuries does not appear to be uniform among all fluoroquinolone users. Advanced age, diabetes mellitus, obesity, renal impairment, and concomitant corticosteroid use were frequently associated with a higher risk of tendon events^(23,32,34,36). These findings are clinically relevant because they indicate that the decision to prescribe fluoroquinolones should consider not only the antimicrobial indication but also the individual profile of tendon vulnerability.

Although most evidence concerns systemic administration, one included study⁽²⁸⁾ suggests that exposures considered to involve lower systemic absorption, such as quinolone-containing optic drops, may also be associated with the risk of Achilles tendon rupture. This finding broadens the discussion of medication safety and indicates that tendon toxicity should be considered in different contexts of quinolone exposure.

Case reports and case series complemented observational studies by describing the clinical course of injuries, including tendinitis, tendinopathy, unilateral or bilateral rupture, functional limitation, need for rehabilitation, and, in some cases, surgical treatment^(27,33,35,37). Although these studies do not permit causal inference, they reinforce the temporal relationship between exposure and clinical manifestation and highlight the potentially severe functional impact of these complications.

Despite warnings issued by international regulatory agencies, the occurrence of tendon events in patients with previously recognized risk factors suggests persistent gaps between safety recommendations and clinical practice⁽²⁶⁾. Therefore, the findings of this review reinforce the need for judicious fluoroquinolone prescribing, particularly among older adults, patients with metabolic or renal diseases, and corticosteroid users, as well as counseling regarding the early recognition of tendon symptoms during and after treatment.

This study has some limitations that warrant acknowledgment. First, the inherent nature of the included hypothesis-generating studies limits causal inferences. Second, a precise characterization of exposure was partially constrained by data missing from the primary literature; specifically, one included study⁽³³⁾ did not specify the exact type of fluoroquinolone administered to the patients. This lack of granularity limits determination of compound-specific risks and prevents a definitive assessment of whether the observed tendon injuries are a class effect or driven by specific generations of the drug.

Conclusion

The available evidence indicates that fluoroquinolone use is associated with an increased risk of Achilles tendon injuries, including tendinopathy, tendinitis, and tendon rupture, particularly during the first weeks after exposure. Risk was higher among older adults, patients with renal impairment,

Table 3. Effect estimates reported by comparative studies assessing the association between fluoroquinolone exposure and Achilles tendon injuries

Author/Year	Outcome	Exposure and comparator	Effect measure	Estimate (95% CI)
Morales et al. (2019)	Achilles tendon rupture	Current systemic fluoroquinolone exposure compared with matched controls and co-amoxiclav exposure	Adjusted incidence rate ratio	3.14 (2.11-4.65)
Persson and Jick (2019)	Achilles tendon rupture	Current fluoroquinolone exposure compared with matched	Adjusted odds ratio	2.71 (1.76-4.17)
Baik et al. (2020)	Achilles tendon rupture	Levofloxacin exposure compared with no exposure to the respective fluoroquinolone	Adjusted hazard ratio	2.20 (1.50-3.24)
Rasmussen et al. (2024)	Achilles tendon lesion or rupture within 90 days	Oral fluoroquinolone exposure compared with amoxicillin exposure	Adjusted hazard ratio	2.74 (1.87-4.02)
Zellers et al. (2024)	Functional recovery after bilateral Achilles tendon rupture	Exposure to fluoroquinolones; no comparator group.	Not applicable	Not applicable
McCullagh et al. (2025)	Achilles tendon lesion or rupture within 1 year	Oral fluoroquinolone exposure compared with amoxicillin exposure	Adjusted hazard ratio	1.49 (1.29-1.73)
Tran et al. (2023)	Achilles tendon rupture	Optic quinolones compared with optic neomycin, oral amoxicillin, or azithromycin	Adjusted hazard ratio	4.49 (1.83-11.02)
Shu et al. (2022)	Tendonitis	Ciprofloxacin reports compared with all other drug-event reports in FAERS	Reporting odds ratio	98.50 (91.52-106.02)
Fleming et al. (2024)	Any tendon injury within 1 month	Fluoroquinolone antibiotics compared with non-fluoroquinolone antibiotics for community-acquired pneumonia	Propensity score-weighted odds ratio	1.42 (1.19-1.70)
Fleming et al. (2025)	Any tendon injury within 1 month	Fluoroquinolone antibiotics compared with non-fluoroquinolone antibiotics for urinary tract infection	Propensity score-weighted odds ratio	1.03 (0.93-1.32)
Anziano (2024)	Bilateral Achilles tendonitis (without rupture)	Levofloxacin.	Not applicable.	Not applicable, as this is a case report.
Gupta and Katiyar (2020)	Fluoroquinolone-associated tendinopathy	Ciprofloxacin exposure among patients with tendinopathy compared with controls without tendinopathy	Odds ratio	2.42 (1.08-5.42)
Alison (2024)	Functional recovery after Achilles tendon rupture	Exposure to fluoroquinolones; no comparator group.	Not applicable	Not applicable, as this is a case report
Chang et al. (2022)	Tendon disorders	Fluoroquinolone exposure compared with no fluoroquinolone exposure	Adjusted hazard ratio	1.42 (1.02-1.87)
Kaneko et al. (2024)	Achilles tendon tendinopathy (without rupture)	Intravenous levofloxacin; no comparator group.	Not applicable	Not applicable, as this is a case report
Anderson et al. (2025)	Complete bilateral rupture of the Achilles tendon treated surgically	Levofloxacin; no comparator group.	Not applicable	Not applicable, as this is a case report
Patel et al. (2024)	Adverse tendon event	Levofloxacin compared with moxifloxacin and ciprofloxacin among fluoroquinolone-treated patients	Incidence comparison	3.1% vs 1.2% vs 0%; p = 0.04

diabetes mellitus, obesity, and concomitant corticosteroid users, reinforcing the need for judicious prescribing and clinical monitoring in individuals with predisposing factors.

Although the findings are consistent, they should be interpreted considering the predominance of retrospective observational studies and case reports, as well as hete-

roogeneity across populations, drugs assessed, diagnostic criteria, and follow-up periods. Prospective studies with well-defined comparator groups and standardized follow-up are recommended to estimate the magnitude of risk more accurately and guide preventive strategies aimed at reducing fluoroquinolone-associated tendon injuries.

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Original Article

Results of wound complications in Achilles tendon repair at a public service

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Abstract

Objective: To evaluate wound healing outcomes and postoperative complications in patients undergoing surgical treatment of Achilles tendon rupture at a Brazilian university hospital operating exclusively through the public healthcare system and to identify factors associated with worse clinical outcomes.

Methods: This retrospective observational study analyzed 64 adult patients with complete Achilles tendon ruptures who underwent surgical treatment between 2019 and 2024. All procedures were performed by orthopedic residents under supervision. Data collected included demographics, comorbidities (smoking, obesity, diabetes), surgical techniques, time to surgery, and wound-related complications. The primary outcome was postoperative complications. Secondary outcomes included time to complete wound healing, rerupture rates, and need for reoperation. Descriptive statistics and inferential analyses were performed with 5% significance ($p < 0.05$).

Results: Mean patient age was 45 years, with 73% aged 40-60 years. Overall complication rate was 20.3%, primarily infection (15.6%) and wound dehiscence (12.5%). Nerve injury occurred in 7.8% and deep infection in 4.7%. No reruptures or tendon exposures were observed. Comorbidities significantly increased the risk of complications (OR ≈ 3.7 , $p < 0.05$) and delayed healing. No significant associations were found between outcomes and patient age, time to surgery, or surgical technique.

Conclusion: Surgical Achilles tendon repair by supervised residents yielded satisfactory outcomes with complication rates comparable to international literature. Comorbidities were the primary risk factors for adverse events, underscoring the need for preoperative optimization. This study validates the safety and effectiveness of the university hospital model when structured supervision and standardized protocols are implemented.

Level of evidence III; Retrospective cohort study.

Keywords: Achilles tendon; Rupture; Postoperative complications; Unified Health System; Hospitals, University.

Introduction

Achilles tendon ruptures (ATR) have emerged as one of the most prevalent tendinous pathologies in contemporary orthopedic practice, demonstrating sustained growth in global incidence over the last few decades⁽¹⁾. It is estimated that ATR accounts for 10.7% of all tendon injuries⁽²⁾, totaling approximately 6 to 7 million new episodes annually⁽³⁾. Recent national registries in Sweden demonstrate a 45% increase in incidence over the last two decades, reaching 41.7 per 100,000 person-years in 2021, with a sharp upward trend

among the population aged 40 and older⁽¹⁾. In the Brazilian context, prospective studies at university reference centers indicate that the injury predominantly affects men (88.6%) in their productive years (mean age 39.5 years), with soccer practice as the primary traumatic mechanism in more than 53% of cases⁽⁴⁾.

The understanding of ATR pathophysiology has evolved to the realization that rupture rarely occurs in healthy tissues. Evidence from 2024 reveals that 46.2% of patients already had a history of previous pain or tendinopathy, suggesting that mechanical failure is the outcome of a chronic and subclinical

Study performed at the Hospital Universitário Ciências Médicas de Minas Gerais, Belo Horizonte, MG, Brazil.

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degenerative process that can present with complete rupture as the first clinical manifestation of tendinopathy⁽²⁾. The injury is concentrated between 2 and 6 cm proximal to the insertion into the calcaneus, a region characterized by critical hypovascularity that compromises tissue regenerative capacity⁽⁵⁾. This biological vulnerability is exacerbated by metabolic disorders that alter the collagen microarchitecture and by the chronicity of repetitive mechanical loading^(1,4).

The treatment of Achilles tendon ruptures remains a field of intense debate. The most recent position statement from the American Orthopaedic Foot & Ankle Society (AOFAS) emphasizes that the choice between surgical and conservative management should be individualized, considering that both approaches can offer satisfactory results provided that non-surgical treatment is initiated early and reserved for cases without a history of previous tendinopathy, as well as non-delaminating and non-insertional ruptures^(5,6). However, robust meta-analysis evidence indicates that surgical intervention is significantly more effective in reducing the risk of a new rupture, presenting a rerupture rate 3.52% lower compared to conservative treatment (relative risk (RR) = 0.44, $p < 0.00001$)⁽⁷⁾. Furthermore, surgery favors a more frequent and rapid return to sports activities, with a success rate 14.44% higher than non-operative management (RR = 1.32; $p = 0.03$)⁽⁷⁾.

However, the functional benefits of the surgical procedure are counterbalanced by an elevated risk of tissue complications. While conservative management is associated with low or minimal rates of cutaneous complications, surgical repair is associated with higher rates of superficial and deep infections, as well as a 3.33% higher risk of nerve injury (RR = 3.67)⁽⁷⁾. Among operative options, minimally invasive repair reduces the risk of superficial infection (0.4% vs. 6.0% in open repair) but maintains the risk of temporary sural nerve injury at around 3.4%⁽⁸⁾. Systemic risk factors such as active smoking (OR = 3.20), obesity (OR = 1.7), and diabetes mellitus (OR = 1.7) act as independent predictors of healing failure and postoperative complications^(7,9).

In university hospitals, the management of these injuries is aggravated by the high complexity of the patients and the prevalence of neglected ruptures, which require reconstruction techniques with higher morbidity^(1,4). Additionally, there is a perception that procedures performed in a teaching environment, with residents acting as primary surgeons, could be associated with higher complication rates. A recent study reported a 40% complication rate in surgeries performed by residents, with resident status identified as an independent risk factor ($p = 0.042$)⁽¹⁰⁾. However, this evidence comes from a single center and does not detail the supervision model employed, limiting the interpretation of the role of structured supervision in standardizing outcomes.

In the healthcare context of Belo Horizonte, the local epidemiological profile and specific complication rates at reference centers of the Unified Health System (Sistema Único de Saúde - SUS) require systematic investigation to substantiate prevention protocols informed by regional

data. Given the gap in recent national evidence on surgical outcomes in SUS university hospitals, an analysis of healing outcomes after Achilles tendon surgeries is warranted to optimize local orthopedic care and evaluate the safety of surgical training in a supervised environment⁽⁴⁾.

Methods

Ethical aspects

The study was approved by the Institutional Review Board in accordance with the CNS Resolution No. 466/12, the guidelines of the National Research Ethics Commission (CONEP), and the principles of the Declaration of Helsinki.

All included participants signed an Informed Consent Form (ICF), obtained in digital or physical format, prior to the use of clinical data. The information was kept confidential and stored in a secure environment (REDCap), with access restricted to the involved researchers.

Study design and setting

This is an observational, retrospective, single-center cohort study based on the analysis of electronic medical records of patients who underwent surgical repair of Achilles tendon rupture at a tertiary care hospital fully dedicated to SUS.

The investigation spanned January 2019 to December 2024 and focused on evaluating healing outcomes following surgical Achilles tendon repair. Due to the institution's nature as a teaching hospital, the surgical interventions were conducted by 3rd-year resident physicians in Orthopedics and Traumatology, or those completing a Fellowship in Foot and Ankle Surgery (4th year of training), assisted and directly supervised by service preceptors, reflecting a setting of tertiary care and specialized professional training.

Study population and selection criteria

The sample consisted of 64 patients, corresponding to all eligible cases identified during the study period; this strategy is justified by logistical feasibility and the dynamics of a regional university center, in accordance with similar prospective national surveys⁽⁴⁾.

Inclusion criteria: The study included individuals aged 18 years or older, diagnosed with complete Achilles tendon rupture, who underwent surgical repair at the Hospital Universitário Ciências Médicas between 2019 and 2024, and whose medical records contained complete clinical and surgical data sufficient to evaluate the outcomes of interest.

Exclusion criteria: Patients under 18 years of age, those without a minimum postoperative outpatient follow-up of 90 days, cases of partial ruptures or other associated tendon injuries, patients undergoing conservative management, patients who refused to sign the ICF, and medical records with inconsistent or missing data regarding surgical wound progression were excluded.

Surgical supervision model

All surgeries were performed by Orthopedics and Traumatology resident physicians (PGY-3 and PGY-4 levels) under the direct supervision of the service's orthopedic surgeon preceptors. The adopted supervision model consisted of:

- **Mandatory preceptor presence:** A preceptor orthopedic surgeon was present in the operating room throughout the entire procedure, scrubbed and ready to intervene when necessary.
- **Level of guidance:** Supervision included continuous verbal guidance and direct manual intervention during critical stages of the procedure (tendon exposure, end-to-end suture, layered closure), depending on the resident's experience and case complexity.
- **Surgical technique selection:** The choice of surgical approach (open repair, open repair with tendon transfer, or minimally invasive repair) was made collaboratively between the resident and the preceptor, taking into account factors such as rupture chronicity, tendon tissue quality, the presence of a significant tendon gap, and resident experience.
- **Technical standardization:** All procedures adhered to standardized institutional protocols, including antibiotic prophylaxis, strict aseptic technique, and uniform postoperative care.

Data collection and variables

Data collection was conducted over five months through the systematic review of electronic medical records from the orthopedics service of a university hospital, involving manual data extraction by two independent researchers and cross-checking to minimize transcription errors. The data were stored in a standardized electronic database using the Research Electronic Data Capture (REDCap) platform, ensuring anonymization, traceability, and access control.

Demographic and clinical variables: Data collected included sex, age, body mass index (BMI), smoking status (active smoker, former smoker, non-smoker), presence of diabetes mellitus (type 1 or type 2, with glycemic control evaluated when available), presence of obesity ($\text{BMI} \geq 30 \text{ kg/m}^2$), mechanism of injury, and time elapsed between injury and surgery.

Surgical variables: The surgical technique employed (minimally invasive/percutaneous repair, end-to-end open repair, or open repair with tendon transfer), tourniquet use, and procedure duration were recorded.

Postoperative protocols: All patients received perioperative antibiotic prophylaxis with a first-generation cephalosporin (cefazolin 2g intravenously 30 minutes prior to incision, with additional doses every 4 hours during the procedure). The immobilization protocol consisted of a short-leg cast in equinus for two weeks, followed by a removable orthosis with gradual release of dorsiflexion. Protected partial weight-bearing in equinus was initiated after 2-3 weeks contingent

upon good surgical wound healing, with progression to full weight-bearing in 6-8 weeks. All patients were referred for physical therapy rehabilitation following the removal of rigid immobilization.

Outcomes: Healing-related complications included surgical wound dehiscence (separation of wound edges with exposure of deep tissues), edge necrosis (cutaneous or subcutaneous necrosis at the wound margins), tendon exposure (direct visualization of the tendon through the wound), and time to complete healing, categorized as either less than or greater than 60 days. Infections were classified as superficial (cellulitis, local erythema, superficial purulent discharge without deep structure involvement) and deep (paratenon involvement, presence of a deep collection, or need for surgical debridement). Neurological events (sural nerve injury manifested by paresthesia or hypoesthesia in the corresponding dermatome) and vascular events (occurrence of deep vein thrombosis (DVT) confirmed by Doppler ultrasound) were also recorded.

The primary study outcome was the occurrence of surgical wound complications (any complication). Secondary outcomes included time to complete healing, rerupture, and the need for surgical reintervention.

Statistical analysis

The collected data were logged in the REDCap platform, exported to a Microsoft® Excel spreadsheet, and initially analyzed using descriptive statistics; graphs, tables, and measures such as means, standard deviations, and percentages were constructed to summarize the data⁽¹¹⁾. The incidence of postoperative outcomes was calculated using point estimates and 95% confidence intervals⁽¹²⁾.

Subsequently, univariate analyses were performed to identify factors associated with both postoperative complications (of any nature) and healing time (less than 2 months vs. equal to or greater than 2 months). Two-tailed hypothesis tests were conducted at the 5% significance level ($\alpha = 0.05$). Univariate analysis assessed the crude associations between the independent variables of interest and the primary outcome. Categorical variables were evaluated using Pearson's chi-square test or Fisher's exact test (when necessary); quantitative variables were evaluated using the non-parametric Mann-Whitney test⁽¹³⁾.

In the final stage, a multivariate analysis was performed using logistic regression to assess postoperative complications (of any type). To identify independent factors associated with the outcome, logistic regression with automatic variable selection, namely Forward Stepwise procedures⁽¹⁴⁾, was applied. Three forward stepwise approaches were used: Forward stepwise (Wald), conditional forward stepwise, and forward stepwise (Likelihood ratio, LR).

The applicability of the logistic regression model for predicting the response variable was evaluated using the Receiver Operating Characteristic (ROC) curve. The ROC curve allows visualization of the model's predictive

performance based on its sensitivity and specificity in relation to the outcome. The area under the ROC curve (AUC) is used to assess model accuracy, that is, the model's ability to correctly identify a given condition. An AUC above 0.9 indicates excellent performance, whereas an AUC between 0.7 and 0.8 is considered acceptable, with good predictive capacity when above 0.8⁽¹⁴⁾.

Results

Analysis of clinical data from patients undergoing Achilles tendon interventions revealed an epidemiological profile concentrated in the 40-60 age group, which accounted for 73% of the study sample. The mean and median age were 45 years, with a standard deviation of 14 years (a coefficient of variation of 31%, indicating moderate age homogeneity among patients) (Figure 1).

Regarding surgical techniques, end-to-end open repair was the predominant approach, applied in 64% of cases (n = 41). Open repair with tendon transfer was performed in 25% of cases (n = 16), generally for chronic ruptures or significant tendon gaps. Minimally invasive repair was utilized in 11% of cases (n = 7).

The evaluation of postoperative outcomes demonstrated an overall complication rate of 20.3% (95% CI: 11.3-32.2%), with a marked predominance of infectious etiology events (15.6%; 95% CI: 7.8-26.9%) and surgical wound dehiscence episodes (12.5%; 95% CI: 5.6-23.2%) (Figure 2, Table 1).

Among the analyzed factors, the presence of comorbidities (smoking, obesity, and diabetes mellitus) emerged as the primary factor associated with worse postoperative outcomes. Patients with at least one of these comorbidities presented a significantly higher risk of complications (50.0% vs. 13.5%; odds ratio [OR] = 3.7; 95% CI: 1.1-12.4; p = 0.011). This impact extended to recovery time, with a significant increase in the incidence of prolonged healing (42% vs. 12%; p = 0.025) in the presence of such clinical conditions. Conversely,

age and the time between injury and surgery showed no statistically significant association with either the occurrence of complications or healing time (Tables 2 and 3).

Among the 64 interventions, isolated open tenoplasty (n = 41) presented dehiscence (n = 6; 14.6%) as the primary complication, along with superficial infection, deep infection, nerve injury, and reapproach (n = 2; 4.9% each), leaving 80.5% (n = 33) of cases complication-free. In the open technique with transfer (n = 16), the most frequent complications were dehiscence, superficial infection, and nerve injury (n = 2; 12.5% each), followed by deep infection (n = 1; 6.2%) and edge necrosis (n = 1; 6.2%), yielding favorable outcomes in 81.2% (n = 13) of cases. The open percutaneous technique (n = 7) registered superficial infection, DVT, and nerve injury (n = 1; 14.3% each), leaving 71.4% (n = 5) of cases complication-free.

Although descriptive data suggest differences in complication rates across surgical techniques, these differences did not reach statistical significance (p > 0.05), likely due to the limited sample size and subgroup heterogeneity.

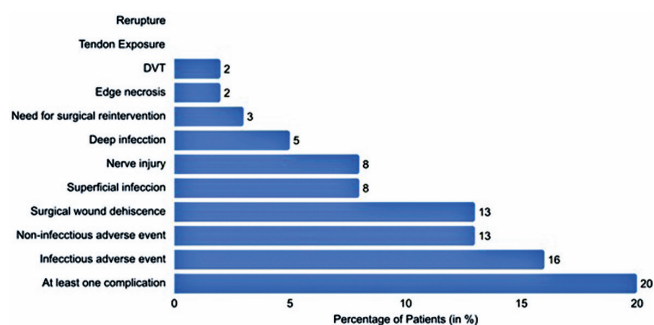


Figure 2. Study's outcomes: Infectious adverse events were predominant.

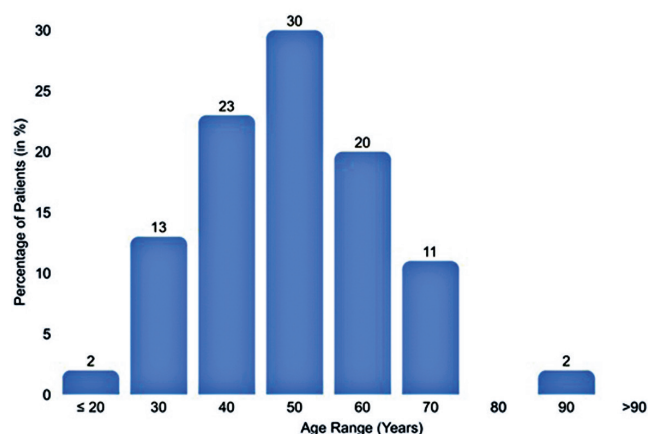


Figure 1. Age distribution of the studied sample (n = 64).

Table 1. Outcomes: 20,3% of the patients had any postoperative complication

Postoperative outcome	Number of cases	Risk	[CI 95%]
At least one complication	13	20.3%	[11.3%; 32.2%]
Infectious adverse event	10	15.6%	[7.8%; 26.9%]
Non-infectious adverse event	8	12.5%	[5.6%; 23.2%]
Surgical wound dehiscence	8	12.5%	[5.6%; 23.2%]
Superficial infection	5	7.8%	[2.6%; 17.3%]
Nerve injury	5	7.8%	[2.6%; 17.3%]
Deep infection	3	4.7%	[1.0%; 13.1%]
Need for surgical re-approach	2	3.1%	[0.4%; 10.8%]
Edge necrosis	1	1.6%	[0.0%; 8.4%]
DVT	1	1.6%	[0.0%; 8.4%]
Tendon exposure	0	0.0%	[0.0%; 5.6%]
Rerupture	0	0.0%	[0.0%; 5.6%]

DVT: Deep vein thrombosis.

Table 2. Univariate analysis of factors associated with postoperative complications

Variable	Categories	Total sample (n = 64)	Complication Yes (n = 13)	Complication risk	Relative risk	p-value
Sex	Female	6 (9%)	1	16.7%	0.8	1.000
	Male	58 (91%)	12	20.7%		
Age over 60 years	Yes	8 (13%)	2	25.0%	1.3	0.660
	No	56 (88%)	11	19.6%		
Patient with any comorbidity	Yes	12 (19%)	6	50.0%	3.7	0.011
	No	52 (81%)	7	13.5%		
Diabetes	Yes	6 (9%)	2	33.3%	1.8	0.593
	No	58 (91%)	11	19.0%		
Smoking	Yes	6 (9%)	3	50.0%	2.9	0.092
	No	58 (91%)	10	17.2%		
Obesity	Yes	1 (2%)	1	100.0%	5.3	0.203
	No	63 (98%)	12	19.0%		
Torniquet use	Yes	60 (94%)	13	21.7%	-	0.574
	No	4 (6%)	0	0.0%		
Surgical technique used	Open with transference	16 (25%)	3	18.8%	1.0	> 0,200
	Minimally invasive	7 (11%)	2	28.6%	1.5	
	Isolated open	41 (64%)	8	19.5%	1.0	

Comorbidity is a significant risk factor ($p < 0.05$)**Table 3.** Univariate analysis of categorical variables for identifying factors associated with healing time

Variable	Categories	Total sample (n = 64)	Equal or greater than 2 months (n = 11)	Less than 2 months (n = 53)	p-value
Sex	Female	6 (9%)	1 (17%)	5 (83%)	1.000
	Male	58 (91%)	10 (17%)	48 (83%)	
Age over 60 years	Yes	8 (13%)	2 (25%)	6 (75%)	0.617
	No	56 (88%)	9 (16%)	47 (84%)	
Patient with any comorbidity	Yes	12 (19%)	5 (42%)	7 (58%)	0.025
	No	52 (81%)	6 (12%)	46 (88%)	
Diabetes	Yes	6 (9%)	2 (33%)	4 (67%)	0.273
	No	58 (91%)	9 (16%)	49 (84%)	
Smoking	Yes	6 (9%)	2 (33%)	4 (67%)	0.273
	No	58 (91%)	9 (16%)	49 (84%)	
Obesity	Yes	1 (2%)	1 (100%)	0 (0%)	0.172
	No	63 (98%)	10 (16%)	53 (84%)	
Torniquet use	Yes	60 (94%)	11 (18%)	49 (82%)	1.000
	No	4 (6%)	0 (0%)	4 (100%)	
Surgical technique used	Open with transference	16 (25%)	4 (25%)	12 (75%)	> 0.200
	Minimally invasive	7 (11%)	0 (0%)	7 (100%)	
	Isolated open	41 (64%)	7 (17%)	34 (83%)	

Therefore, the findings of this study indicate that, within the evaluated context, Achilles tendon surgeries yielded globally satisfactory outcomes, but they reinforce the importance

of identifying and appropriately managing comorbidities during the perioperative period to reduce complications and promote faster healing.

Variables identified as statistically significant and clinically relevant in the univariate analysis were included in the multivariate logistic regression model. In this adjusted model, comorbidities remained an important factor associated with postoperative complications. The ROC curve for the logistic regression model predicting postoperative complications demonstrated moderate discriminative capacity, with an area under the curve (AUC) below 0.80 (Figure 3).

Discussion

The present study reported an overall complication rate of 20.3% after surgical treatment of acute Achilles tendon rupture at a public university hospital. The most frequent adverse events were infectious and wound-healing complications, with infection occurring in 15.6% of cases and wound dehiscence in 12.5%. Although clinically relevant, these findings are consistent with previously reported complication profiles after open Achilles tendon repair. Prior studies have reported wound complication rates ranging from 10% to 25%, with superficial infections in 5% to 10% and deep infections in 2% to 5% of cases⁽¹⁵⁻¹⁷⁾. In this context, the observed deep infection rate of 4.7% falls within expected ranges.

The overall complication rate is also comparable to prior literature, indicating that complications after Achilles tendon repair are relatively common. A systematic review and network meta-analysis including 2,060 patients reported a major complication rate of 9.13%, with rerupture, deep infection, and DVT as the most clinically significant outcomes⁽¹⁸⁾. The higher rate observed in this cohort may be attributed to the inclusion of both major and minor complications, the predominance of open surgical techniques, and the characteristics of a real-world population within a public healthcare system. Therefore, these results likely reflect the inherent susceptibility of this procedure to wound-related morbidity rather than suboptimal outcomes.

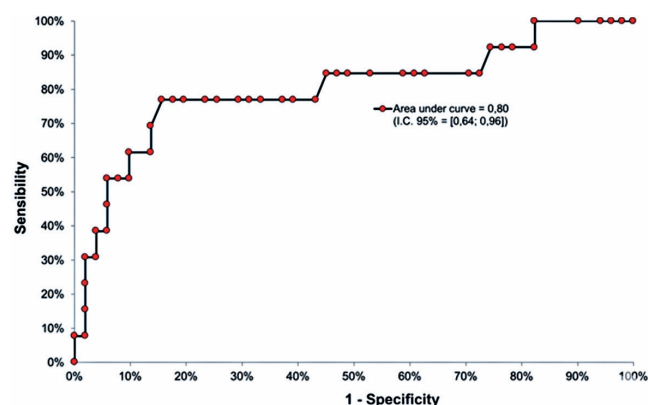


Figure 3. ROC curve considering the logistic regression model for predicting postoperative complications.

A key aspect of this study is that all procedures were performed by resident physicians under direct supervision. Teaching hospitals are often perceived as environments with greater surgical variability or a higher risk of complications. However, the findings suggest that, when appropriate supervision, standardized techniques, and institutional protocols are in place, outcomes remain comparable to those reported internationally. This supports the role of university hospitals as both training centers and safe providers of specialized orthopedic care.

The healthcare setting is also relevant. All patients were treated within a hospital integrated into the Brazilian Unified Health System. Public institutions frequently face challenges related to resource availability, operating room logistics, and follow-up limitations, as well as the need to manage patients with greater clinical complexity. Despite these constraints, complication rates remained within the ranges reported in the literature, suggesting that surgical outcomes depend not only on access to advanced technology but also on organization, protocol adherence, and team training^(8,9).

Patient-related risk factors played a significant role in the occurrence of complications. Comorbidities such as smoking, obesity, and diabetes mellitus were associated with a significantly increased risk of postoperative complications (OR $\approx$ 3.7) and delayed healing. These findings are consistent with previous reports. Trivedi et al.⁽¹⁹⁾ identified obesity, diabetes, hyperlipidemia, hypertension, female sex, and older age as predictors of complications and reoperation following Achilles tendon repair. The association between smoking and wound complications has also been well established, as demonstrated by Stavenuiter et al.⁽¹⁷⁾.

Regarding surgical technique, open repair has been associated with higher rates of wound complications, whereas minimally invasive approaches may reduce wound morbidity but carry a higher risk of sural nerve injury^(7,10,11). In this study, no statistically significant differences in complication rates were observed between techniques, possibly due to the limited sample size and reduced statistical power.

The absence of rerupture in this cohort is noteworthy. Rerupture is one of the most concerning complications and is typically reported in 2% to 5% of surgically treated patients, with higher rates in some nonoperative series^(12,18). While this finding may reflect adequate surgical technique and postoperative management, it should be interpreted with caution, as the minimum follow-up of 90 days may not capture late reruptures or long-term functional deficits⁽²⁰⁾.

Another relevant aspect is the institutional improvement observed during the study period. The implementation of laminar airflow systems and increased involvement of the Hospital Infection Control Committee may have contributed to improved surgical safety. Although causality cannot be established due to the retrospective design, these measures align with established principles of infection prevention. In public teaching hospitals, such interventions are particularly

valuable because they are cost-effective and rely primarily on organizational practices rather than expensive technologies.

This study has several limitations. Its retrospective design introduces potential selection and information bias and limits causal inference. The relatively small sample size, especially for subgroup comparisons, may have reduced statistical power. Although multivariate analysis was performed, residual confounding cannot be excluded. Additionally, the minimum follow-up of 90 days may be insufficient to detect late complications. The absence of a comparator group, such as nonoperatively treated patients or procedures performed exclusively by senior surgeons, further limits conclusions regarding the independent effect of resident participation.

Despite these limitations, the study provides valuable real-world evidence from a resource-constrained public teaching hospital. Achilles tendon repairs performed by supervised residents demonstrated complication rates consistent with international data. The predominance of wound and infectious complications reinforces the importance of patient optimization, careful surgical technique, and infection-prevention strategies. The absence of rerupture or tendon exposure supports the safety of supervised training environments.

Conclusion

Surgeries for the treatment of Achilles tendon rupture performed in a university hospital serving the public system demonstrated complication rates consistent with the international literature, even when performed by resident physicians in training and using exclusively resources provided by the Unified Health System.

Adverse events were predominantly related to infectious and healing complications, and were heavily influenced by the presence of conditions such as smoking, obesity, and diabetes mellitus. This underscores the importance of preoperative clinical optimization in patients with comorbidities to achieve satisfactory postoperative progress. The results reinforce that the combination of proper supervision, technical standardization, and institutional improvements—including the implementation of laminar flow in the operating room and enhanced oversight by the CCIH—can ensure safe and effective outcomes, even in resource-limited teaching environments. Consequently, the study demonstrates that SUS university hospitals can deliver surgical care of a quality equivalent to international standards while simultaneously fulfilling their fundamental mandate of training specialists.

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Original Article

High prevalence of intra-articular lesions identified by arthroscopy during syndesmotic screw removal after ankle fracture fixation

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Abstract

Objective: To determine the prevalence of intra-articular lesions and evaluate syndesmotic stability using ankle arthroscopy performed at the time of syndesmotic screw removal in patients with surgically treated Weber B and C ankle fractures.

Methods: A prospective observational study was conducted, including patients with unstable ankle fractures classified as Weber B or C who underwent open reduction and internal fixation with syndesmotic screw placement. Ankle arthroscopy was performed during routine syndesmotic screw removal 6–8 weeks after the index procedure. Arthroscopic findings, including chondral lesions of the talar dome, synovitis, intra-articular fibrosis, meniscoid lesions, loose bodies, and syndesmotic instability, were recorded. Chondral lesions were classified according to the Outerbridge classification.

Results: Twenty-two patients were included in the study. Arthroscopic evaluation revealed chondral lesions of the talar dome in 16 patients (72.7%), synovitis in 17 patients (77.3%), and diffused intra-articular fibrosis in 20 patients (90.9%). Residual syndesmotic instability was identified in two patients (9.1%). Most chondral lesions were classified as Outerbridge grade II or III. No statistically significant association was identified between mechanism of injury and arthroscopic findings.

Conclusion: Arthroscopy evaluation during syndesmotic screw removal revealed a high prevalence of intra-articular lesions following ankle fracture fixation. Arthroscopic evaluation may therefore represent a valuable diagnostic and therapeutic adjunct for identifying intra-articular lesions that may contribute to persistent postoperative symptoms.

Level of Evidence IV; Prospective Observational Study.

Keywords: Ankle fractures; Ankle arthroscopy; Syndesmotic instability; Osteochondral lesion; Talar dome.

Introduction

Ankle fractures are among the most common injuries treated by orthopedic surgeons, with an estimated incidence of approximately 174 per 100,000 individuals annually⁽¹⁾. Population-based studies have also demonstrated important epidemiological variations and associations between patient characteristics and fracture patterns⁽²⁾.

Despite advances in surgical fixation techniques, postoperative complications and functional limitations remain relatively

frequent after ankle fracture surgery^(3,4). In addition, intra-articular lesions such as chondral lesions, synovitis, loose bodies, and fibrotic bands are commonly associated with ankle fractures and may contribute to persistent postoperative symptoms. Several arthroscopic studies have reported intra-articular lesions in up to 70% of ankle fractures, emphasizing the importance of evaluating the ankle joint beyond fracture reduction alone⁽⁵⁻⁷⁾. In particular, osteochondral lesions of the talar dome have been reported in a high proportion of patients with ankle fractures⁽⁶⁾.

Study performed at the Hospital General Dr. Manuel Gea Gonzalez, Ciudad de México, México.

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Although magnetic resonance imaging (MRI) can detect osteochondral injuries, ankle arthroscopy remains the gold standard for direct visualization of intra-articular pathology and allows simultaneous treatment of detected lesions⁽⁸⁾.

In addition, arthroscopy provides a dynamic assessment of the distal tibiofibular joint and may help identify subtle syndesmotic injuries that are not always evident on conventional imaging⁽⁹⁾.

Recent studies have suggested that arthroscopically assisted fixation of ankle fractures may improve the detection of intra-articular pathology without increasing complication rates⁽¹⁰⁾. Because syndesmotic screws are frequently removed after fracture healing, arthroscopy performed at the time of screw removal represents a valuable opportunity to evaluate the ankle joint and identify associated intra-articular pathology.

The objective of this study is to determine the prevalence of intra-articular lesions and evaluate syndesmotic stability using ankle arthroscopy at the time of syndesmotic screw removal in patients with surgically treated Weber B and C ankle fractures.

Methods

Study design

A prospective observational study was conducted to evaluate the prevalence of intra-articular lesions in patients with surgically treated ankle fractures. Arthroscopic evaluation was performed at the time of routine syndesmotic screw removal following open reduction and internal fixation (ORIF).

The study was conducted at a general hospital for a period of 36 months. Institutional ethical approval was obtained prior to study initiation, and all patients provided informed consent for participation.

Patients were eligible for inclusion if they were aged ≥ 18 years, had an acute unstable ankle fracture classified as Danis-Weber B or C, underwent surgical treatment with ORIF, received a syndesmotic screw during the index procedure, and had planned syndesmotic screw removal between 6 and 8 weeks postoperatively. Patients were excluded if they had a history of previous ankle surgery, open fractures, pilon fractures, pathological fractures, incomplete clinical data, or refused to participate. A total of 22 consecutive patients met the inclusion criteria and were included in the analysis.

Fracture classification and mechanism of injury: Fractures were classified according to the Danis-Weber classification system based on preoperative radiographs. The mechanism of injury was determined using the Lauge-Hansen classification, which categorizes fractures as Supination-External Rotation (SER) and Pronation-External Rotation (PER).

Radiographic evaluation included standard anteroposterior, lateral, and mortise views of the ankle.

Surgical technique and arthroscopic evaluation: All patients underwent ORIF of the ankle fracture according to standard surgical techniques. Syndesmotic instability was evaluated

intraoperatively, and fixation was performed using a trans-syndesmotic screw when indicated.

Routine removal of the syndesmotic screw was performed 6–8 weeks after the index procedure. At the time of screw removal, ankle arthroscopy was performed using standard anteromedial and anterolateral portals. Arthroscopic evaluation included systematic inspection of the talar dome, tibial plafond, medial and lateral gutters, and syndesmotic recess.

The presence of intra-articular pathology was recorded, including chondral lesions of the talar dome, synovitis, diffuse intra-articular fibrosis, meniscoid lesions, loose bodies, and syndesmotic instability. Chondral lesions were classified according to the Outerbridge classification system, and the anatomical distribution of talar dome lesions was documented using the Raikin nine-zone classification^(11,12).

The primary outcome of the study was the prevalence of intra-articular lesions detected by ankle arthroscopy.

Statistical analysis

Statistical analysis was performed using SPSS software (version 20.0; IBM Corp., Armonk, NY, USA).

Descriptive statistics were used to summarize patient demographics and arthroscopic findings. Continuous variables were expressed as mean $\pm$ standard deviation, whereas categorical variables were reported as absolute frequencies and percentages.

The association between the mechanism of injury (SER vs PER) and arthroscopic findings was evaluated using the chi-square (χ^2) test. A p-value < 0.05 was considered statistically significant.

Results

A total of 22 patients met the inclusion criteria and were included in the analysis. The mean age was 33.1 ± 7.2 years (range, 17–46 years). Thirteen patients (59.1%) were male, and nine (40.9%) were female. Fourteen fractures (63.6%) occurred in the right ankle and eight (36.4%) in the left ankle.

Fractures were classified as Weber B in 16 patients (72.7%) and Weber C in 6 patients (27.3%). According to the Lauge-Hansen classification, the most common mechanism of injury was SER-IV, which occurred in 18 patients (81.8%), followed by PER-IV in four patients (18.2%). Patient demographics, fracture characteristics, and mechanisms of injury are summarized in Table 1.

Arthroscopic evaluation performed at the time of syndesmotic screw removal revealed a high prevalence of intra-articular pathology. Chondral lesions of the talar dome were identified in 16 patients (72.7%), making them the most common intra-articular finding.

Synovitis was observed in 17 patients (77.3%), while diffuse intra-articular fibrosis was present in 20 patients (90.9%). Other less frequent findings included meniscoid lesions in three patients (13.6%) and loose bodies in one patient (4.5%).

Arthroscopic findings are summarized in Table 2. Representative arthroscopic findings are shown in Figure 1.

The anatomical distribution of talar dome lesions was analyzed according to the Raikin nine-zone classification. Most lesions were in the anteromedial and central regions of the talar dome (zones 2 and 3). The distribution of chondral lesions according to the Raikin⁽¹¹⁾ classification is illustrated in Figure 2.

Among the 16 patients with chondral lesions, the severity of cartilage damage was classified according to the Outerbridge

classification⁽¹²⁾. The most common grades were Outerbridge grade II (31.2%) and grade III (37.5%), indicating partial-thickness cartilage damage or deep fissuring. Outerbridge grades I and IV were observed less frequently. The severity distribution of chondral lesions is summarized in Table 3.

The relationship between the mechanism of injury (SER vs PER) and arthroscopic findings was evaluated using the chi-square test. No statistically significant association was found between the injury mechanism and the presence of chondral lesions, synovitis, or diffuse fibrosis ($p > 0.05$).

However, residual syndesmotic instability was more frequently observed in PER injuries, although this difference did not reach statistical significance. The results of the chi-square analysis are presented in Table 2.

Table 1. Patient demographics, fracture characteristics, and mechanism of injury (n = 22)

Variable	Value
Age (years), mean $\pm$ SD (range)	33.1 $\pm$ 7.2 (17–46)
Male	13 (59.1%)
Female	9 (40.9%)
Right ankle	14 (63.6%)
Left ankle	8 (36.4%)
Supination–External Rotation (SER IV)	18 (81.8%)
Pronation–External Rotation (PER IV)	4 (18.2%)
Weber B	16 (72.7%)
Weber C	6 (27.3%)

Discussion

The present study demonstrated a high prevalence of intra-articular pathology in patients with surgically treated ankle fractures. Arthroscopic evaluation performed at the time of syndesmotic screw removal revealed chondral lesions in 72.7% of patients, diffuse intra-articular fibrosis in 90.9%, and synovitis in 77.3% of cases. These findings confirm that intra-articular damage remains highly prevalent even after anatomical fracture reduction.

Ankle fractures are among the most common injuries treated by orthopedic surgeons and represent a significant

Table 2. Association between mechanism of injury and arthroscopic findings (Chi-square analysis)

Arthroscopic finding	SER (n = 18)	PER (n = 4)	Total n (%)	χ^2	p-value
Chondral lesion	13	3	16 (72.7)	0.04	0.84
Synovitis	14	3	17 (77.3)	0.02	0.88
Diffuse fibrosis	17	3	20 (90.9)	0.41	0.52
Meniscoid lesion	2	1	3 (13.6)	0.89	0.34
Loose bodies	1	0	1 (4.5)	0.25	0.62
Syndesmotic instability	1	1	2 (9.1)	3.12	0.07

SER: Supination–External Rotation; PER: Pronation–External Rotation.

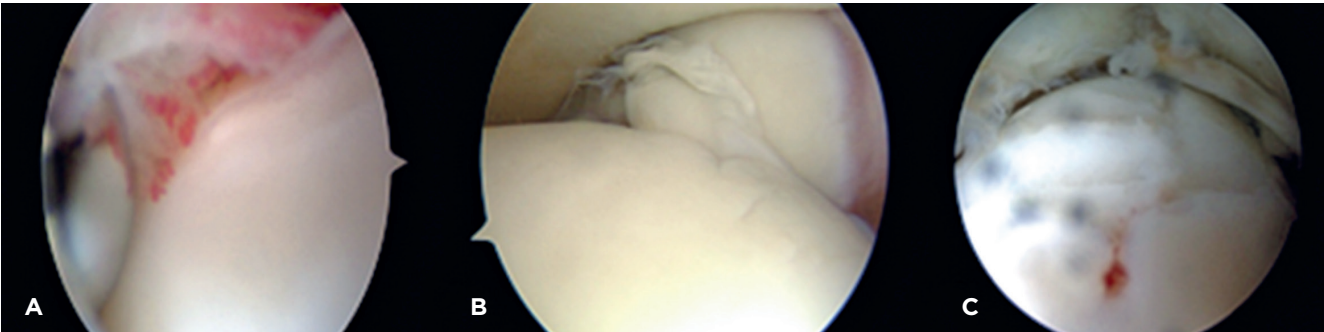
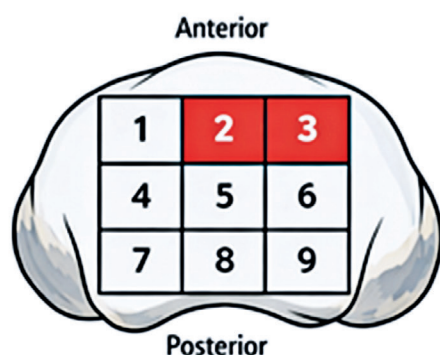


Figure 1. Arthroscopic findings (A) synovitis of the anterior ankle joint, (B) chondral lesion of the talar dome, and (C) fibrotic intra-articular band causing anterior ankle impingement.

**Table 4.** Distribution of chondral lesions by Raikin zones.

Zone	Patients	Percentage
1	0	0%
2	6	27%
3	6	27%
4	0	0%
5	0	0%
6	0	0%
7	0	0%
8	0	0%

Figure 2. Distribution of talar dome chondral lesions according to the Raikin nine-zone classification, showing most lesions located in zones 2 and 3.**Table 3.** Severity of chondral lesions according to the Outerbridge classification (n = 16)

Outerbridge grade	Description	n	%
Grade I	Cartilage softening	3	18.8
Grade II	Partial-thickness fissures	5	31.2
Grade III	Deep fissuring	6	37.5
Grade IV	Exposed subchondral bone	2	12.5

cause of long-term functional impairment. Population-based studies have reported an incidence of approximately 174 per 100,000 individuals per year, highlighting the clinical relevance of optimizing their management⁽¹⁾. Epidemiological studies have also demonstrated associations between patient characteristics and fracture patterns in surgically treated ankle fractures⁽²⁾. In addition, complications following ankle fracture surgery remain relatively common and may negatively affect functional recovery⁽³⁾. Several factors have been identified as potential contributors to these adverse outcomes, including soft-tissue conditions at the time of injury and the mechanism of trauma⁽⁴⁾. In a recent multicenter propensity score-matched analysis (TRON study), Sugino et al.⁽¹³⁾ reported that delayed surgical treatment after ankle fracture was associated with worse functional outcomes and a higher incidence of complications. These findings highlight the multifactorial nature of postoperative recovery after ankle fractures and emphasize the importance of identifying additional factors that may contribute to persistent symptoms, including unrecognized intra-articular pathology.

Several arthroscopic investigations have demonstrated a high prevalence of osteochondral lesions associated with ankle fractures. In one of the largest arthroscopic series,

Hintermann et al.⁽⁵⁾ reported osteochondral lesions of the talar dome in approximately 63% of patients with acute ankle fractures. Similarly, Lambers et al.⁽⁶⁾ described osteochondral lesions in up to 70% of ankle fractures, emphasizing the importance of intra-articular evaluation in these injuries. These findings are consistent with the present study, in which chondral lesions were identified in 72.7% of patients, as shown in Table 4.

Comparable results were reported by Chen et al.⁽⁷⁾, who observed intra-articular cartilage lesions in approximately 72% of patients undergoing arthroscopic evaluation of acute ankle fractures. Similar findings were reported by Aktas et al.⁽¹⁴⁾, who found a high incidence of talar dome cartilage lesions in patients with ankle fractures. The consistency of these findings across multiple studies suggests that osteochondral injury is a common consequence of ankle trauma and may contribute to persistent postoperative symptoms and the development of post-traumatic osteoarthritis.

Although MRI can detect osteochondral injuries with reasonable sensitivity, arthroscopy remains the gold standard for evaluating intra-articular pathology. Arthroscopy allows direct visualization of cartilage surfaces, synovial tissue, and fibrotic structures while also permitting simultaneous treatment of detected lesions. This advantage is particularly relevant in patients presenting with persistent postoperative symptoms despite apparently satisfactory radiographic findings⁽⁸⁾.

In the present study, residual syndesmotic instability was identified in 9.1% of patients. Accurate assessment of the distal tibiofibular joint remains challenging using conventional imaging modalities. Arthroscopic evaluation allows dynamic evaluation of the syndesmosis and may detect subtle instability that cannot be identified using radiographs alone. Arthroscopic correlates of subtle syndesmotic injuries have been previously described by Guyton et al.⁽⁹⁾.

Table 4. Comparison of the prevalence of chondral lesions reported in previous arthroscopic studies

Study	Year	Study design	n	Arthroscopy timing	Chondral lesions (%)
Hintermann et al.	2000	Prospective	288	Acute fracture	63
Lambers et al.	2021	Retrospective	100	Acute fracture	70
Chen et al.	2019	Prospective	86	Acute fracture	72
Aktas et al.	—	Retrospective	52	Acute fracture	68
Present study	2025	Prospective	22	Screw removal	72.7

Diffuse intra-articular fibrosis was frequently observed in our cohort. Post-traumatic fibrosis and scar tissue formation have been described as potential causes of anterior ankle impingement and chronic postoperative pain following ankle fracture surgery. Arthroscopic debridement of fibrotic bands may therefore play an important role in the management of patients with persistent symptoms after ankle fracture fixation⁽¹⁵⁾.

In recent years, increasing attention has been directed toward arthroscopically assisted fixation of ankle fractures. A systematic review and meta-analysis by Zhuang et al.⁽¹⁶⁾ demonstrated that arthroscopically assisted fixation improves detection of intra-articular pathology without increasing complication rates. Similarly, recent evidence suggests that ankle arthroscopy performed in association with fracture fixation does not increase complication rates compared with conventional treatment methods⁽¹⁰⁾.

Despite these advantages, the routine use of arthroscopy in all ankle fractures remains controversial. Additional prospective studies with larger sample sizes and long-term

functional follow-up are required to determine whether systematic arthroscopic evaluation improves clinical outcomes.

This study has several limitations. First, the sample size was relatively small. Second, arthroscopy was performed at the time of syndesmotic screw removal rather than during the initial fracture fixation procedure. Finally, long-term functional outcomes were not evaluated. Despite these limitations, the routine use of arthroscopy in all ankle fractures remains controversial, and additional studies with larger patient cohorts and long-term follow-up are required.

Conclusion

Arthroscopic evaluation during syndesmotic screw removal revealed a high prevalence of intra-articular lesions following ankle fracture fixation. These findings highlight the potential role of ankle arthroscopy as a valuable diagnostic and therapeutic adjunct for identifying and managing intra-articular lesions that may contribute to persistent postoperative symptoms.

Authors' contributions: Each author contributed individually and significantly to the development of this article: ACA *(<https://orcid.org/0000-0002-6129-954X>) Conceptualization, study design, surgical procedures, manuscript drafting, manuscript revision; JARG *(<https://orcid.org/0009-0003-9938-4074>) Methodology, data collection, statistical analysis, interpretation of data, manuscript drafting; ACKM *(<https://orcid.org/0000-0003-2457-9654>) Supervision and critical revision of the manuscript. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) 

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Original Article

Influence of proximal hip muscle strengthening on medial longitudinal arch alignment: A randomized trial comparing gluteus maximus and gluteus medius exercises

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Abstract

Objective: To compare the effects of gluteus maximus (GMax) strengthening versus gluteus medius (GMed) strengthening on medial longitudinal arch (MLA) alignment in individuals with asymptomatic flexible flatfoot.

Methods: Fifty-three individuals with asymptomatic flexible flatfoot were randomly assigned to two groups for this randomized comparative study. GMax strengthening activities were assigned to Group A, and GMed exercises to Group B. For two weeks, both therapies were administered. The navicular drop test (NDT) and foot posture index (FPI), evaluated before and after the intervention, were among the outcome measures. SPSS version 26.0 was used for statistical analysis, and $p < 0.05$ was used for both within-group and between-group comparisons.

Results: After the intervention period, both groups showed statistically significant reductions in FPI scores and navicular decrease ($p < 0.05$). When comparing the GMed and GMax strengthening groups, the between-group analysis showed a considerably greater improvement in MLA alignment ($p < 0.05$). In individuals with asymptomatic flexible flatfoot, proximal hip muscle strengthening improves MLA alignment. The significance of focused hip abductor strengthening in the treatment of flexible flatfoot is evident, as GMed strengthening appears more successful than GMax strengthening in improving foot posture and reducing navicular drop.

Conclusion: Gluteus maximus and gluteus medius strengthening improved the medial longitudinal arch and foot posture in asymptomatic flexible flatfoot; however, gluteus medius strengthening was more effective, emphasizing the importance of hip abductor-focused protocols in physiotherapy.

Level of Evidence II; Randomized trial, Comparative study.

Keywords: Flexible flatfoot; Foot posture index; Navicular drop test; Gluteus medius; Gluteus maximus; Medial longitudinal arch.

Introduction

The medial longitudinal arch (MLA) of the foot plays an important role in shock absorption, weight distribution, and efficient gait mechanics. Flexible flatfoot, characterized by MLA collapse during weight-bearing that reappears in non-weight-bearing positions, is a common foot posture variation observed in both pediatric and adult populations⁽¹⁾. Although often asymptomatic, flexible flatfoot has been associated

with altered lower-limb biomechanics and may predispose individuals to future musculoskeletal disorders of the foot, ankle, knee, and hip⁽²⁾.

Traditional rehabilitation approaches for flexible flatfoot have primarily focused on intrinsic foot muscle strengthening, orthotic support, and interventions targeting the ankle-foot complex. However, emerging evidence highlights the role of proximal segments of the kinetic chain in influencing distal

Study performed at the Datta Meghe College of Physiotherapy, Nagpur, Maharashtra, India.

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joint alignment and foot posture⁽³⁾. The concept of regional interdependence suggests that impairments at the hip can alter lower-limb kinematics, including excessive femoral internal rotation and adduction, which in turn may increase pronator forces at the subtalar joint and contribute to MLA collapse⁽⁴⁻⁶⁾.

The gluteal muscle group, particularly the gluteus maximus (GMax) and gluteus medius (GMed), plays a critical role in controlling frontal- and transverse-plane movements of the lower limb. The GMed functions as a primary hip abductor and pelvic stabilizer during single-limb stance, while the GMax contributes significantly to hip extension and external rotation. Weakness or delayed activation of these muscles has been associated with increased dynamic knee valgus, excessive foot pronation, and altered plantar pressure distribution⁽⁷⁻⁹⁾.

Despite growing interest in proximal strengthening strategies, there remains a paucity of comparative studies evaluating the differential effects of specific gluteal muscle strengthening on foot posture parameters⁽¹⁰⁾. Limited evidence exists comparing the influence of GMax versus GMed strengthening on MLA alignment in individuals with flexible flatfoot.

Therefore, the objective of this study is to evaluate and compare the effects of GMax and GMed strengthening exercises on MLA alignment in individuals with asymptomatic flexible flatfoot. It was hypothesized that proximal hip muscle strengthening would result in significant improvements in foot posture, with GMed strengthening demonstrating superior outcomes due to its critical role in frontal-plane pelvic and lower-limb stability.

Methods

The present study was conducted as a randomized comparative experimental trial to evaluate and compare the effects of proximal hip muscle strengthening on MLA alignment. The study was conducted in the Department of Physiotherapy at a tertiary-care teaching institute in Maharashtra, India. All assessments and interventions were conducted under the supervision of qualified physiotherapists. Before the trial started, the study was approved by the Institutional Review Board, and ethical guidelines were followed throughout.

Sample size was calculated using the following formula:

$$n = \frac{2(Z_{\alpha} + Z_{\beta})^2}{d^2}$$
 Where, n = required sample size per group, Z_{α} = standard normal deviate for significance level $\alpha = 0.05$ (1.96), Z_{β} = standard normal deviate for desired power of 80% (0.84), d = effect size (0.8), $n = 24.5$. Since sample sizes must be whole numbers, round up; $n = 25$ per group, but to stay conservative and match software-based rounding (as done in Statsmodels), we use: $n = 26$ per group, the formula used for adjusted sample size (n_{adj}) is $n_{adj} = \frac{n}{1 - \text{Dropout rate}}$ adjust

for 10% dropouts, $n_{adj} = \frac{26}{1 - 0.10} = \frac{26}{0.90} = 28.89$,
 $n_{adj} = 29$ participants per group

After the study's methodology, potential benefits, and risks were outlined, each participant provided written informed consent.

A total of 70 participants diagnosed with asymptomatic flexible flatfoot were recruited for the study using a convenience sampling method as shown in Table 1. Participants were screened based on predefined inclusion and exclusion criteria. Individuals aged between 18 and 30 years with asymptomatic flexible flatfoot, positive navicular drop test (NDT), ability to understand and follow exercise instructions, and willing to participate and provide written informed consent. Excluded participants had a history of foot or ankle surgery, recent lower limb injury or trauma within the past six months, neurological disorders affecting gait or posture, structural or rigid flatfoot deformities, current use of foot orthoses or participation in any lower limb strengthening program.

Participants were randomly allocated into two groups using a computerized randomization method. Allocation was concealed in envelopes and single-assessor blinded to ensure equal distribution of participants between the groups: Group A (GMax Strengthening Group), 26 participants, and Group B (GMed Strengthening Group), 27 participants. Outcome measures were assessed at two points: baseline assessment and post-intervention (After two weeks). All measurements were taken by the same assessor to minimize inter-rater variability (Figure 1).

Outcome measures

The NDT was used to assess changes in the MLA height. The vertical distance of the navicular tuberosity from the floor was measured in a subtalar neutral non-weight-bearing position and then in a relaxed weight-bearing position. The difference between the two measurements was recorded in millimeters. Higher values indicated greater navicular drop and increased foot pronation⁽¹¹⁾.

Table 1. Interventional protocol

Group A (Gluteus Maximus strengthening)	Group B (Gluteus Medius strengthening)
Prone hip extension for a week, then progress with the TheraBand exercise	Progressive clamshell for a week, then progress with the TheraBand exercise
Common exercises for both groups (Figures 4E and 4F)	
Foot range of motion exercises (Figure 4A-D)	
Toe curls (Figure 4E)	
Foot gripping exercise (Figure 4F)	
Calf raises	
Quantity: 3 sets of 15 repetitions for 2 weeks, 12 sessions (6 per week)	Quantity: 3 sets of 15 repetitions for 2 weeks, 12 sessions (6 per week)

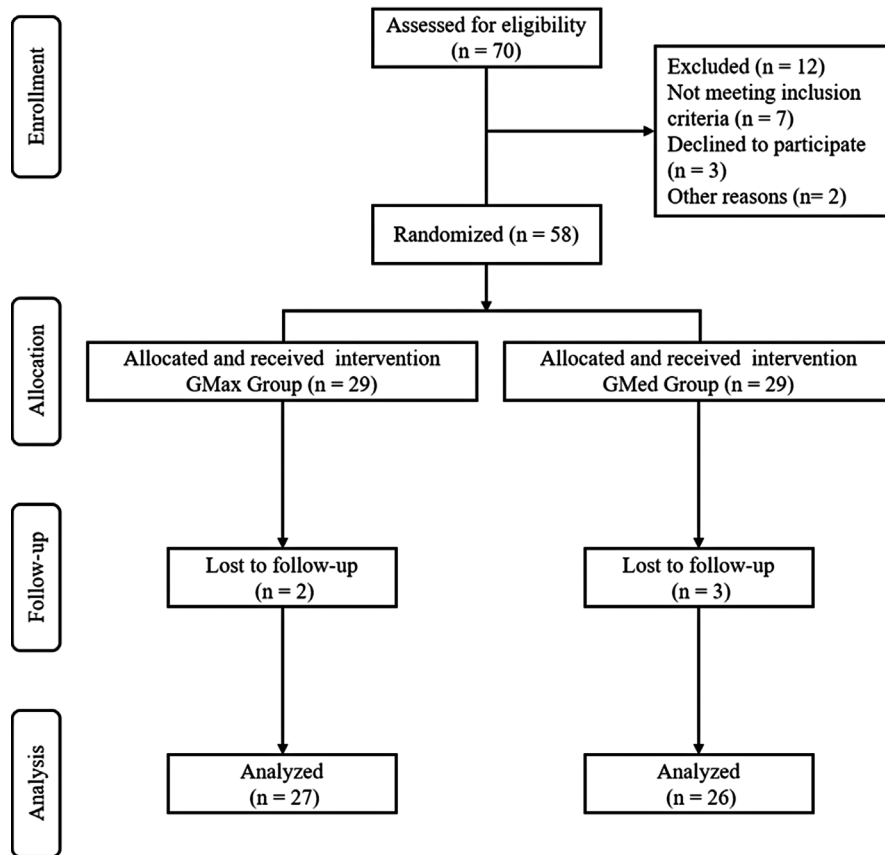


Figure 1. Randomized allocation process.

The foot posture index (FPI) was used to assess static foot posture. It consists of six criteria evaluating rearfoot and midfoot alignment in the sagittal, frontal, and transverse planes. The total scores range from -12 (extremely supinated) to +12 (strongly pronated), with each criterion being evaluated on a scale from -2 to +2. A more pronated foot position is indicated by higher scores⁽¹²⁾.

Intervention protocol

Both groups underwent supervised exercise interventions for two weeks, with exercises performed five days per week as shown in Table 1. Each session lasted approximately 20-25 minutes.

Group A – GMax strengthening⁽¹³⁾

Participants in Group A performed exercises targeting the GMax muscle, including: Prone hip extension exercises progressing to resistance-based hip extension using Theraband. With suitable rest times in between sets, each exercise was performed in 2-3 sets of 10-15 repetitions, as shown in Figures 2A and 2B.

Group B – GMed strengthening

Participants in Group B performed exercises focusing on the GMed muscle, including: Clamshell, which was progressed after one week with Theraband. Each exercise was performed in 2-3 sets of 10-15 repetitions, with progression based on participant tolerance, as shown in Figures 3A and 3B.

Statistical analysis

Data were analyzed using IBM SPSS Statistics version 26.0. Descriptive statistics were calculated for demographic variables. The data normality was evaluated using the Shapiro-Wilk test. Paired t-tests were used for within-group comparisons, and independent samples t-tests were used for between-group comparisons. The statistical significance threshold was set at $p < 0.05$.

Results

A total of 53 individuals with asymptomatic flexible flatfoot successfully finished the research. Participants were randomly assigned to two groups: Group A (GMax strengthening, $n = 26$)



Figure 2. (A) Prone hip extension for Group A (B) Prone hip extension with Theraband for Group A.



Figure 3. (A) Clamshell exercise for Group B (B) Clamshell exercise with Theraband for Group B.

and Group B (GMed strengthening, $n = 27$). There were no statistically significant differences ($p > 0.05$) in baseline demographic characteristics (Table 2) and outcome indicators between the two groups, suggesting baseline homogeneity.

Within-group comparisons

Compared with baseline data (Table 3), individuals in Group A showed a statistically significant decrease in NDT scores after the two-week intervention, as shown in Figure 5A ($p < 0.05$). Furthermore, after the intervention, FPI scores significantly improved toward a more neutral foot posture as shown in Figure 5B ($p < 0.05$), indicating improved MLA alignment. Group B exhibited statistically significant improvements in both outcome measures following the intervention period, as shown in Table 4. Navicular drop values were significantly reduced post-intervention compared to baseline, as shown in Figure 6A ($p < 0.05$). Similarly, FPI scores demonstrated a significant shift toward neutral alignment, reflecting reduced foot pronation as shown in Figure 6B ($p < 0.05$).

Table 2. Demographic data

Variables	Gluteus Maximus Group ($n = 27$) (mean $\pm$ standard deviation)	Gluteus Medius Group ($n = 26$) (mean $\pm$ standard deviation)	p-value
Age	23.37 $\pm$ 3.92	24.58 $\pm$ 3.46	0.24
Gender	1.55 $\pm$ 0.50	1.53 $\pm$ 0.50	0.90
BMI	24.75 $\pm$ 4.31	25.16 $\pm$ 5.09	0.78

BMI: Body mass index.

Between-group comparisons

Between-group analysis revealed statistically significant differences (Table 5) in favor of Group B (GMed strengthening). The magnitude of reduction in NDT values was significantly greater in Group B compared to Group A ($p < 0.05$), as shown in Figure 7. Likewise, improvements in FPI scores were significantly greater in Group B (GMed strengthening) than Group A (GMax strengthening), as shown in Figure 8 ($p < 0.05$).

Discussion

The present study aimed to compare the effects of GMax and GMed strengthening on MLA alignment in individuals with asymptomatic flexible flatfoot. The findings demonstrated that although both intervention protocols resulted in significant improvements in navicular drop and FPI, GMed strengthening produced comparatively superior outcomes. These findings support the growing body of evidence suggesting that proximal muscle strength training can positively influence distal joint alignment through the interconnected kinetic chain of the lower extremity⁽³⁾.

Table 3. Within-group analysis for Gluteus Maximus strengthening group

Outcome measure	Pre-test (mean ± standard deviation)	Post-test (mean ± standard deviation)	p-value
Navicular drop right (mm)	11.96 ± 1.37	10.37 ± 1.15	<0.001*
Navicular drop left (mm)	12.22 ± 1.37	10.37 ± 1.21	<0.001*
Foot posture index right side	7.48 ± 1.16	6.07 ± 1.30	<0.001*
Foot posture index left side	7.30 ± 1.27	5.56 ± 1.37	<0.001*

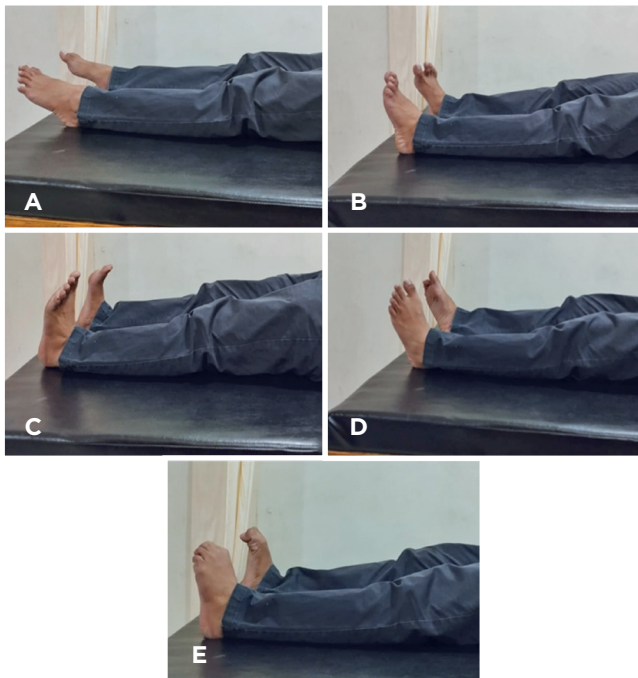


Figure 4. (A) Foot range of motion exercises—ankle plantarflexion (B) Foot range of motion exercises—ankle eversion (C) Foot range of motion exercises—ankle dorsiflexion (D) Foot range of motion exercises—ankle inversion (E) Toe curl exercise.

The biomechanical basis for proximal strengthening influencing foot posture can be explained by the concept of regional interdependence, wherein alterations at the hip affect kinematics at the knee and ankle due to the closed kinetic chain relationship of the lower limb⁽⁶⁾. Proximal hip muscle weakness, particularly of the gluteus muscle, has been associated with increased femoral internal rotation and adduction, leading to compensatory tibial internal rotation and excessive subtalar joint pronation⁽⁵⁾. These altered mechanics increase stress on the MLA, contributing to its collapse in individuals with flexible flatfoot. Recent literature has consistently demonstrated that proximal hip muscle strengthening can improve foot posture, medial arch height, balance, and functional outcomes by restoring optimal lower-limb alignment⁽³⁻⁹⁾.

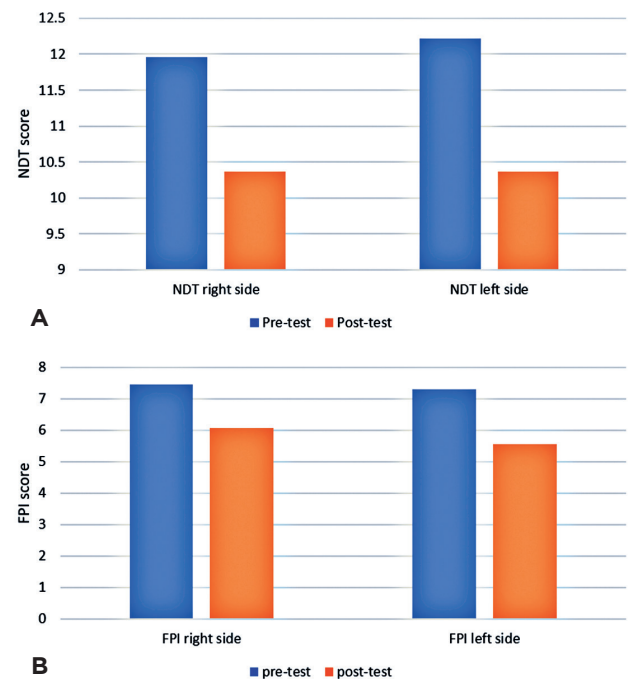


Figure 5. (A) Within-group analysis of NDT score for Group A (B) Within-group analysis of FPI score for Group A.

Table 4. Within-group analysis for Gluteus Medius strengthening group

Outcome measure	Pre-test (mean ± standard deviation)	Post-test (mean ± standard deviation)	p-value
Navicular drop right (mm)	12.00 ± 1.36	9.58 ± 1.30	<0.001*
Navicular drop left (mm)	12.00 ± 1.30	9.65 ± 0.98	<0.001*
Foot posture index right side	7.62 ± 1.24	4.77 ± 1.51	<0.001*
Foot posture index left side	7.15 ± 1.32	4.46 ± 1.07	<0.001*

Several studies within the last five years support the role of gluteal strengthening in improving MLA parameters. A randomized controlled trial by Engkananuwat and Kanlayanaphotporn (2023) demonstrated that a hip-strengthening program emphasizing the GMed resulted in significant reductions in navicular drop and improvements in foot posture compared to foot exercises alone, indicating the dominant influence of the hip abductors on foot alignment⁽⁸⁾. Similarly, Raghav et al. (2024)⁽⁹⁾ reported that GMed strengthening combined with intrinsic foot muscle training led to greater improvements in FPI and balance compared to GMax-focused interventions, reinforcing the functional importance of the GMed in controlling pronation during weight-bearing tasks.

The superior effectiveness of GMed strengthening observed in the present study may also be explained by its functional role in daily activities. The GMed is highly active during walking, stair negotiation, single-limb stance, and postural stabilization, which are frequently performed activities in the 18-30-year age group included in this study⁽¹⁴⁾. In contrast, the GMax demonstrates peak activation primarily during high-intensity tasks such as jumping, sprinting, and landing, which may not be consistently engaged in routine daily activities⁽¹⁵⁾. As the participants in the present study were asymptomatic and physically active young adults, GMed strengthening likely

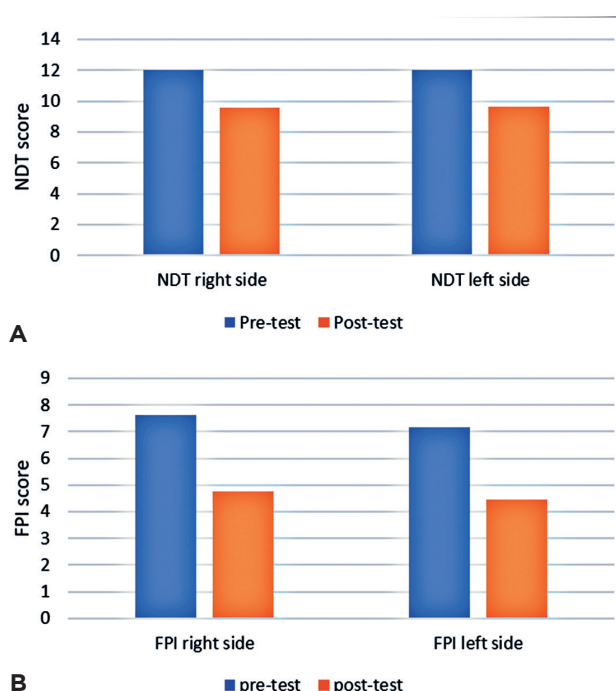


Figure 6. (A) Within-group analysis of NDT score for Group B (B) Within-group analysis of FPI score for Group B.

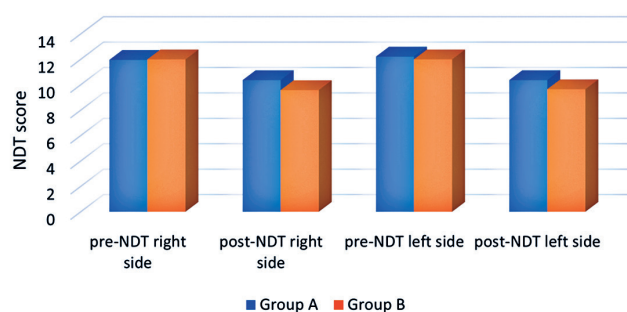


Figure 7. Post-test comparison between groups of NDT score.

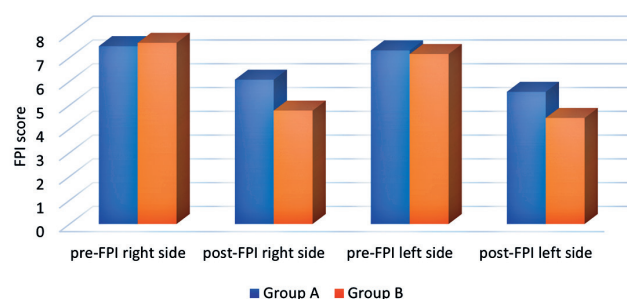


Figure 8. Post-test comparison between groups of FPI score.

Table 5. Within-group analysis for Gluteus Medius strengthening group

Outcome variable	Gluteus Maximus (Mean ± standard deviation)	Gluteus Medius (Mean ± standard deviation)	p-value	Effect size
Pre-intervention Navicular drop right side (mm)	11.96 ± 1.37	12 ± 1.36	0.922	-0.03
Post-intervention Navicular drop right side (mm)	10.37 ± 1.15	9.58 ± 1.30	0.023*	0.64
Pre-intervention Navicular drop left side (mm)	12.22 ± 1.37	12 ± 1.30	0.547	0.16
Post-intervention Navicular drop left side (mm)	10.37 ± 1.21	9.65 ± 0.98	0.026*	0.65
Pre-intervention Foot posture index right side	7.48 ± 1.16	7.62 ± 1.24	0.685	-0.12
Post-intervention Foot posture index right side	6.07 ± 1.30	4.77 ± 1.51	0.001*	0.92
Pre-intervention Foot posture index left side	7.30 ± 1.27	7.15 ± 1.32	0.690	0.12
Post-intervention Foot posture index left side	5.56 ± 1.37	4.46 ± 1.07	0.003*	0.89

Confidence interval = 95%, p-value ≤ 0.05*

translated more directly into functional improvements during habitual weight-bearing activities, thereby producing greater changes in MLA alignment.

Another important factor contributing to the observed improvements over a short intervention period is the physiological phases of strength training⁽¹⁶⁾. Neuromuscular adaptations rather than muscle growth are primarily responsible for early strength improvements, especially during the first 2-3 weeks. Improved motor unit recruitment, synchronization, firing frequency, and neuromuscular coordination are among these changes⁽¹⁷⁾. These modifications lead to increased joint stability and muscle efficiency without appreciable increases in muscle cross-sectional area⁽¹⁸⁾. Improved neuromuscular control of the external rotators and hip abductors can quickly reduce abnormal lower-limb kinematics in the setting of flexible flatfoot, thereby reducing pronator loads at the foot and improving MLA alignment. This mechanism explains why significant improvements were seen in the current research within the comparatively brief 2-week intervention period.

The quick response to treatment may also be explained due to flexible flatfoot in the group under study is asymptomatic. The musculoskeletal system may have responded more effectively to corrective strengthening exercises since these people did not have long-standing neuromuscular deficits, structural deformities, or persistent discomfort. Additionally, because short-duration intervention techniques increase exercise program adherence and lower dropout rates, they may be especially beneficial in asymptomatic individuals. The need for ongoing or progressive strengthening programs to sustain long-term benefits is highlighted because neuromuscular changes from short-term training may be temporary and reversible if activity is reduced⁽¹⁹⁾.

The lack of a nonintervention control group in the current investigation was a crucial methodological factor. Rather than comparing the efficacy of exercise with no therapy, the main goal was to examine the relative efficacy of two active strengthening regimens. Additionally, the study population consisted of young adults enrolled in college, and it was thought to be difficult to recruit and retain participants in a nontreatment control group because of their academic obligations and decreased motivation to participate in the absence of an intervention.

The fact that both intervention groups were given a similar program of intrinsic foot exercises, such as calf lifts, foot curls, foot rolling, and active range of motion exercises, is crucial to consider when evaluating the current results. By increasing intrinsic foot muscle activation and arch stiffness, these workouts can independently enhance medial longitudinal arch height and foot posture, according to prior research. Therefore, rather than only hip-strengthening therapies, these common exercises may have contributed to some of the improvement shown in both groups. However, given the foot training regimen was the same for both groups, the GMed group's better results suggest an additional advantage of focused GMed strengthening.

On the other hand, even though GMax strengthening produced notable gains, its primary role in sagittal-plane movement and high-force exercises may explain its relatively smaller impact on MLA alignment⁽¹⁴⁾. Compared with the GMed, enhanced GMax strength had less impact on sustained frontal-plane control during single-limb stance, even though it does contribute to total lower-limb stability and propulsion. The results of the current study are further supported by a randomized trial by Aiswarya et al. (2024)⁽²⁰⁾, which showed that hip abductor-focused training produced superior improvements in alignment-related outcomes while GMax strengthening improved lower-limb power and functional performance.

According to this study, young individuals with asymptomatic flexible flatfoot may benefit greatly from proximal hip strengthening, specifically targeting the GMed, to improve MLA alignment. The amount of improvement seen in this trial seems to be clinically significant beyond statistical significance. Participants in the GMed group showed a discernible shift toward a less pronated foot posture, with a mean decrease of almost 2.4 mm in navicular drop and nearly 3 points on FPI scores. The mechanical efficiency of the foot during weight-bearing activities may be enhanced by even small improvements in medial longitudinal arch alignment, which may decrease excessive strain on the tibialis posterior tendon, spring ligament, and plantar fascia. Such modifications are especially crucial in asymptomatic people, as the aim of the intervention is prevention rather than symptom alleviation. Plantar fasciitis, patellofemoral pain syndrome, shin splints, and progressive collapsing foot deformity are among the problems that may be prevented in the future by improving early foot posture and reducing cumulative biomechanical stress across the lower kinetic chain. As a result, in addition to being statistically significant, the gains seen may also be clinically important adaptations that promote long-term musculoskeletal health and injury prevention.

The results support the use of short-term, functionally appropriate exercise regimens to improve adherence and early biomechanical rectification and highlight the need to integrate proximal strengthening techniques into flatfoot care procedures.

This study has several limitations that should be considered when interpreting the findings. First, the absence of a non-intervention or foot-exercise-only control group limits the ability to determine whether the observed improvements were solely attributable to GMax or GMed strengthening. Since both groups performed the same intrinsic foot exercise program, improvements in medial longitudinal arch measures may have been partially influenced by these common exercises. Second, the intervention and follow-up period were limited to two weeks, preventing evaluation of the long-term sustainability of the observed changes and whether these improvements persist after cessation of training.

Third, the sample consisted exclusively of young adults with asymptomatic flexible flatfoot, which restricts the

generalizability of the findings to symptomatic individuals, pediatric populations, older adults, or athletes with higher functional demands. Fourth, outcome measures were limited to static assessments and therefore did not capture dynamic biomechanical adaptations during gait or functional activities

A limitation of the present study was the absence of a non-intervention control group. The primary objective was to compare the effectiveness of two active strengthening interventions rather than to evaluate exercise against no treatment. Furthermore, the study population consisted of college-going young adults, making recruitment and

retention of participants in a no-treatment group challenging due to academic commitments and reduced willingness to participate without receiving an intervention.

Conclusion

Gluteus maximus and gluteus medius strengthening improved the medial longitudinal arch and foot posture in asymptomatic flexible flatfoot; however, gluteus medius strengthening was more effective, emphasizing the importance of hip abductor-focused protocols in physiotherapy.

Authors' contributions: Each author contributed individually and significantly to the development of this article: RA *(<https://orcid.org/0000-0001-9012-3933>) Conceived and planned the activities that led to the study, and wrote the paper; ND *(<https://orcid.org/0009-0008-2599-487X>) Interpreted the results, participated in reviewing and finalising the manuscript; MK *(<https://orcid.org/0000-0001-6781-8446>), MS *(<https://orcid.org/0000-0001-7416-4663>), and AB *(<https://orcid.org/0009-0008-3256-9409>) Participated in reviewing process. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) 

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Original Article

A new method for measuring hindfoot alignment: Reliability and temporal stability

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Abstract

Objective: To evaluate the interobserver reliability and temporal stability of an adapted Van Dijk-Asaumi method for measuring coronal hindfoot alignment.

Methods: A cross-sectional, analytical, and prospective study including 42 adults without clinically apparent foot deformities. Weight-bearing radiographs were obtained in the anteroposterior, profile, and long axial views of the calcaneus. Hindfoot alignment was measured using a novel adapted method by Van Dijk-Asaumi and assessed by four evaluators with different levels of experience. Interobserver reliability and test-retest reliability were assessed using the intraclass correlation coefficient (ICC). The standard error of measurement (SEM) and the minimal detectable change (MDC) were also calculated. Additionally, Bland-Altman analysis was performed, and Lin's concordance correlation coefficient was determined.

Results: Interobserver reliability was moderate, with ICC values ranging from 0.54 to 0.61. Test-retest reliability demonstrated adequate temporal stability, with ICC values between 0.57 and 0.61. The SEM was low (0.12°-0.14°), with an MDC below 0.4°. Bland-Altman analysis revealed negligible systematic bias and narrow limits of agreement. Lin's concordance correlation coefficient indicated near-perfect agreement (0.996-0.997). The adapted method demonstrated low measurement error and adequate temporal stability, though only moderate interobserver reliability (ICC 0.54-0.61).

Conclusions: The novel method demonstrated low measurement error, adequate temporal stability, and moderate overall interobserver agreement, establishing itself as a practical, objective, and reliable alternative for the quantitative assessment of hindfoot alignment in clinical practice.

Level of evidence III; Methodological, Cross-sectional, Analytical, and Prospective Study.

Keywords: Talus; Calcaneus; Foot deformities; Observer variation; Reference values.

Introduction

The posterior region of the foot, formed by the talus and calcaneus bones, is known as the hindfoot. It is delimited by the tibiotalar joint and the transverse tarsal joint distally⁽¹⁾. It stands out as an important region for weight-bearing distribution and alignment between the ankle and forefoot, contributing to impact absorption and gait biomechanics⁽²⁾.

To compare ankle deformities in patients with significant orthopedic complaints, it is paramount to understand what

constitutes a healthy, function-preserved foot. Therefore, the alignment of a healthy foot presents an aligned calcaneus, with no significant deviation in valgus or varus, allowing the line of the leg axis to be aligned with the center of the calcaneus and the medial longitudinal arch to maintain the proper height, providing adequate functionality with good impact absorption and adequate weight distribution⁽³⁻⁵⁾.

Deformities in valgus and varus present high morbidity, thus interfering with the patient's quality of life. The valgus hindfoot has the calcaneus deviated medially, with support

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from the medial edge of the foot, and is often associated with conditions such as flatfoot⁽³⁾. This contributes to the appearance of hyperpronation gait and medial arch collapse, often clinically, with important pain syndrome, in addition to causing tendinitis of the posterior tibialis, while in the varus hindfoot, the calcaneus is laterally deviated, with the support on the lateral edge of the foot, thus associated with the existence of the cavus foot⁽³⁾. It presents with a rigid gait with less impact absorption, predisposing to sprain.

In this context, changes in the hindfoot interfere with the entire kinetic chain of movement, affecting joints such as the knee and hip that are part of the lower limbs' movement; the final route of these deformities is degeneration, loss of function, and pain⁽⁶⁾. Thus, it is understandable that there is concern among orthopedists, especially foot and ankle specialists, about determining these deformities not only qualitatively through clinical examination but also quantitatively to achieve a more objective and grounded management approach.

In the radiographic evaluation, changes in angular parameters objectively indicate hindfoot deformities, providing greater safety in evaluation and clinical decision-making. Studies have shown the superiority of radiographic measurements regarding the use of the goniometer in clinical examination⁽⁷⁻⁹⁾ (Figure 1).

It is important to note that weight-bearing anteroposterior (AP) and profile (P) radiographs of the ankle are not applicable due to the overlapping of bones⁽¹⁰⁾, there are other views to measure these deformities, but they are not routinely used in clinical practice due to the technical requirements for their execution. In this context, a long view of the calcaneus relates the calcaneus to the leg and prioritizes visualization of the subtalar joint, making it an excellent view for the analysis and surgical planning of patients with angular hindfoot deformities⁽¹¹⁾.



Figure 1. Hindfoot ectoscopy.

Although the Van Dijk method is validated and widely cited, its practical application is limited because it requires identifying two specific anatomical points on the calcaneus (at 30 mm and 7 mm from the distal surface), which can introduce variability among observers and hinder its adoption in clinical practice. The proposed adaptation, called the Van Dijk-Asaumi method, aims to reduce this variability by replacing the first point with the crossing of the tibial axis with the subtalar joint, thereby simplifying the process while maintaining technical rigor.

Given the above, this study has as its primary objective to evaluate the interobserver reliability and temporal stability of an adaptation of the Van Dijk method (called Van Dijk-Asaumi) to measure the hindfoot coronal alignment. As a secondary objective, to correlate the measurements obtained by this adapted method with conventional radiographic parameters of the foot (Kite, Meary, and calcaneal pitch angles) to characterize the studied sample.

Methods

A cross-sectional, analytical, and prospective study was conducted in the orthopedics outpatient clinic of a tertiary hospital in São Bernardo do Campo, SP, Brazil, after approval by the Institutional Review Board. Data were collected after signing the Informed Consent Form and obtained from the institutional electronic medical record, as authorized by the institution.

Individuals aged 18 years or older, without apparent clinical deformities in the foot and ankle and without musculoskeletal comorbidities that could interfere with the hindfoot alignment, were included. Patients unable to maintain weight-bearing support, non-ambulators, or those who did not agree to participate in the study were excluded.

The sample size was defined based on reliability studies using the intraclass correlation coefficient (ICC). Considering an expected ICC of 0.60, 80% power, a 5% significance level, and two measurements per individual, the calculation indicated the inclusion of at least 40 participants. To compensate for possible losses, 42 individuals were recruited.

Weight-bearing radiographs were obtained in the AP, P, and long axial views of the calcaneus. In Van Dijk's method⁽¹²⁾, an existing method for visualizing hindfoot alignment, a cassette box with a Plexiglas surface was used, with a radiation source configuration of 4 mAs and 50 kV, a focal length of 100 cm, and the beam directed at the ankle joint.

To record the long axial view, the film cassette was laid on the floor. The volunteers stood on the cassette and were asked to maintain a dorsal ankle flexion of 10°, which was verified with a goniometer. The beam configurations were the same as the hindfoot alignment view, but the beam inclination angle was 45° to the ground (Figure 2).

Both feet were positioned in internal rotation so that they were parallel, and images were taken in bilateral posture, with the feet positioned 80mm apart and the medial edges of the feet parallel.

For radiographic measurements (Figure 3), according to Van Dijk, the mid-diaphyseal tibial axis is traced by dividing the tibia into two mid-diaphyseal points 30 mm apart and extending the line distally.

The calcaneal axis is traced by connecting:

- First: The midpoint of a horizontal line 30mm proximal to the most distal part of the calcaneus.
- Second: At 7 mm from the most distal part of the calcaneus, a horizontal line is drawn and divided in a 40%/60% ratio, with the 40% length measured from the lateral face.

For the proposed adapted method (Van Dijk-Asaumi), the mid-diaphyseal tibial axis is traced as originally described. For the calcaneal axis, the first anatomical point is defined as the intersection of the axis line of the distally extended tibia and the subtalar joint, radiographically identified as the articular space between the talus and the calcaneus. The second point is defined 7 mm from the most distal surface of the calcaneus, on a horizontal line. From the lateral face, a 40%/60% ratio is traced, and the resulting point is connected to the first point to form the calcaneal axis. The backfoot angle is formed by the intersection of the two axes (Figure 4).

In addition to this method, conventional radiographic parameters of the foot were measured, including talocalcaneal angle (Kite) in AP and P views, Meary's angle in AP and P views, and calcaneal pitch in both feet.

The images were independently assessed by four evaluators with different levels of experience in foot and ankle, including a foot and ankle specialist with ten years of experience, a foot and ankle specialist with five years of experience, a fellow orthopedist (Resident level 4) in foot and ankle surgery, and a first-year resident in orthopedics and traumatology. Each evaluator performed all measurements without access to the others' results. For radiographic sample characterization, the Kite, Meary, and calcaneal pitch angles were initially obtained separately for each evaluator and each foot. Then, the mean of the four evaluations was calculated for each parameter, and these values were used to describe the sample data. The results were expressed as the mean and standard deviation, separately for the right and left feet.

The reliability of the Van Dijk-Asaumi method was assessed from the individual measures of each evaluator. Interobserver reliability was estimated using the intraclass correlation coefficient (ICC) with the two-way random, absolute agreement, single-measure (ICC2) model. The test-retest reliability was evaluated by repeating the measurements after one month, with recalculation of the ICC2 to assess the method's temporal stability. The standard error of measurement (SEM) was calculated from the ICC, and the minimum detectable error (MDC) was estimated as $MDC = 1.96 \times \sqrt{2} \times SEM$. The agreement between the measures was also evaluated using Bland-Altman charts, which are used to



Figure 2. Long axis of the calcaneus, according to Reilingh et al.⁽¹⁾

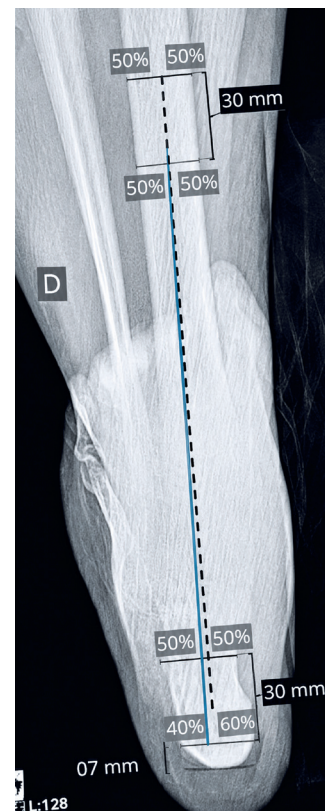


Figure 3. Original Van Dijk method.

identify possible systematic biases between the evaluators and the limits of agreement between the measurements. All statistical analyses were performed using Jamovi software version 2.6.44.0.

Results

Forty-two individuals were included, with a mean age of 48.3 ± 15.1 years and a mean body mass index of 27.2 ± 5.1 kg/m². The sample had a balanced sex distribution, with 21 men (50.0%) and 21 women (50.0%). Regarding skin color, 18 participants (42.9%) were classified as white and 24 (57.1%) as non-white (Table 1).

The radiographic characterization of the sample is detailed in Table 2, where mean values compatible with structurally normal feet are observed, including Kite, Meary, and calcaneal pitch angles within the reference ranges described in the literature. Thus, these results confirm that the sample consisted of feet radiographically within normal standards.

The reliability of the Van Dijk-Asaumi method is presented in Table 3. The interobserver reliability, assessed using the ICC2, was 0.54 (95% CI, 0.15-0.76) for the right foot and 0.61

(95% CI, 0.22-0.80) for the left foot, indicating moderate interrater agreement. The test-retest reliability was also moderate, with ICC2 values of 0.57 (95% CI, 0.16-0.78) in the right foot and 0.61 (95% CI, 0.20-0.80) in the left foot. The SEM was low for both sides, with values of 0.14° for the right foot and 0.12° for the left, corresponding to MDCs of 0.40° and 0.34°, respectively. These results indicate that variations of less than approximately 0.4° can be attributed to the measurement error of the method. The values of the backfoot angle obtained by the Van Dijk-Asaumi method were, in the right foot, a mean of $2.3^\circ \pm 1.1^\circ$ (amplitude: -0.5° to 4.8°) and, in the left foot, a mean of $2.4^\circ \pm 1.0^\circ$ (amplitude: -0.3° to 4.9°). These values represent the normal range in a population without apparent deformities and serve as a preliminary reference for future studies (Table 3).

The concordance analysis by the Bland-Altman method confirmed the high temporal stability of the method (Figure 5). For the right foot, the mean bias between test and retest

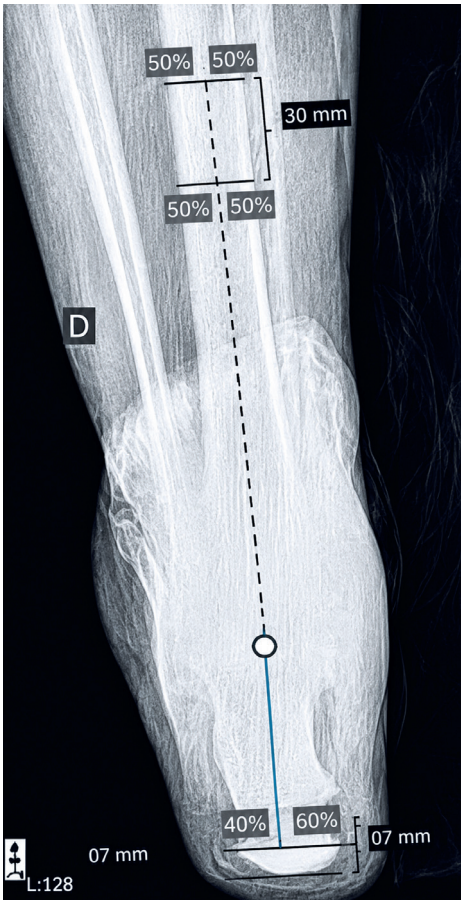


Figure 4. Proposed Van Dijk-Asaumi method.

Table 1. Sociodemographic and clinical characteristics of the sample (n = 42)

Variable	n (%) or mean $\pm$ SD	Min-Max
Age (years)	48.3 $\pm$ 15.1	22-75
BMI (kg/m ²)	27.2 $\pm$ 5.13	18.7-37.2
Sex		
Female	21 (50.0)	-
Male	21 (50.0)	-
Skin color		
White	18 (42.9)	-
Non-white	24 (57.1)	-

SD: Standard deviation; BMI: Body mass index

Table 2. Radiographic characterization of the feet (n = 42)

Parameter	Right foot	Left foot
Anteroposterior talocalcaneal angle (Kite) (°)	33.0 $\pm$ 1.5	32.9 $\pm$ 1.6
Profile talocalcaneal angle (Kite) (°)	25.5 $\pm$ 1.9	25.5 $\pm$ 1.8
Anteroposterior Meary angle (°)	0.54 $\pm$ 0.79	0.57 $\pm$ 0.80
Profile Meary angle (°)	0.52 $\pm$ 0.85	0.51 $\pm$ 0.80
Calcaneal pitch angle (°)	22.9 $\pm$ 1.4	22.9 $\pm$ 1.4

Values expressed as mean $\pm$ standard deviation.

Table 3. Reliability of the Van Dijk-Asaumi method

Analysis	Right foot	Left foot
Interobserver (ICC2)	0.54 (0.15-0.76)	0.61 (0.22-0.80)
Test-retest (ICC2)	0.57 (0.16-0.78)	0.61 (0.20-0.80)
SEM (°)	0.14	0.12
MDC (°)	0.40	0.34

Note: Values presented as ICC (95% CI), SEM: Standard error of measurement; MDC: Minimum detectable change.

was $+0.006^\circ$, with limits of agreement from -0.08° to $+0.10^\circ$, demonstrating the absence of systematic bias and low dispersion of differences. For the left foot, the mean bias was -0.010° , with limits of agreement from -0.09° to $+0.07^\circ$, with a similar pattern. On both sides, the points showed a homogeneous distribution around the zero line, with no proportional tendency or heteroscedasticity.

In addition, Lin's concordance correlation coefficient was 0.996 for the right foot and 0.997 for the left foot, indicating almost perfect agreement between the test and retest measurements. Altogether, these findings demonstrate that the Van Dijk-Asaumi method presents high temporal stability, low measurement error, and excellent overall agreement, even when applied by evaluators with different levels of experience (Figure 5).

Discussion

The present study evaluated the reliability and temporal stability of the adapted Van Dijk-Asaumi method to measure the hindfoot coronal alignment. The results showed that the method has low measurement error, excellent temporal stability, and near-perfect test-retest agreement, even when applied by evaluators with different levels of experience. These findings reinforce the potential of the method as a reproducible and clinically useful tool, corroborating the search for simplified and reliable radiographic techniques for hindfoot evaluation, as explored in the literature⁽¹³⁾.

In recent years, weight-bearing computed tomography (WBCT) has been considered the gold standard for three-dimensional assessment of hindfoot alignment. However, its high cost, limited availability, and greater radiation exposure limit its use as a first-line exam. The simple radiographic method proposed here supports relevant clinical analysis, especially in resource-limited services, as a screening examination and for longitudinal follow-up.

The radiographic characterization of the sample, which included measures such as Kite and Meary angles, confirmed that the individuals studied had feet structurally within normal

parameters⁽¹³⁾. Establishing this baseline in a population without major deformities is very important, as it minimizes the influence of extreme anatomical variations, allowing to test the accuracy of the measurement method under more controlled and clinically relevant conditions.

The interobserver reliability of the method presented moderate values that, although not reaching the range considered excellent according to some criteria⁽¹⁴⁾, are compatible with the performance observed in other radiographic methods of hindfoot alignment that depend on the manual identification of anatomical points^(1,15). Although we have not made a direct comparison between the Van Dijk-Asaumi method and established radiographic methods (original Van Dijk, Saltzman hindfoot alignment view) or with WBCT, it is possible to contextualize our findings with the literature. Reilingh et al.⁽¹⁾ reported ICCs of 0.61-0.77 for the long axial view of the calcaneus, while Saltzman and El-Khoury⁽⁸⁾ found ICCs of 0.58-0.68 for the hindfoot alignment view. The main justification for the proposed adaptation lies in simplifying the identification of anatomical points. While Van Dijk's original method requires the demarcation of 30 mm from the distal surface of the calcaneus, a technically challenging and error-prone procedure, especially in bones with irregular morphology, our adaptation uses the crossing of the tibial axis with the subtalar joint. This anatomical point is consistently visualized in the long axial view of the calcaneus, and its identification requires less geometric inference from the evaluator. Although the interrater reliability of the adapted method (ICC 0.54-0.61) was only moderate and did not exceed the values reported for the original method, we believe that simplifying the process can facilitate training new raters and reduce variability in clinical settings with varying levels of experience. Future studies with a direct comparison design between the two methods are needed to test this hypothesis.

In practice, small variations between observers are common, especially when they involve professionals at different stages of training⁽¹⁵⁾. Therefore, moderate reliability reflects more the inherent variability of image interpretation than an intrinsic limitation of the proposed protocol.

On the other hand, the high temporal stability of the method, as measured by the Bland-Altman analysis⁽¹⁶⁾, showed practically no bias and narrow limits of agreement, with values much lower than the estimated MDC. Lin's concordance correlation coefficient close to 1 reinforces this observation, indicating almost perfect agreement between measurements taken at different times. These findings suggest that when the technique is repeated under the same conditions, the method produces highly consistent results, a key attribute for serial clinical monitoring of patients.

From a clinical point of view, the low magnitude of the measurement error is particularly relevant. An MDC of less than 0.4° indicates that small angular variations, but greater than this threshold, observed in serial examinations, have a high probability of representing real changes in hindfoot alignment, and not method fluctuations⁽¹⁶⁾. This suggests that

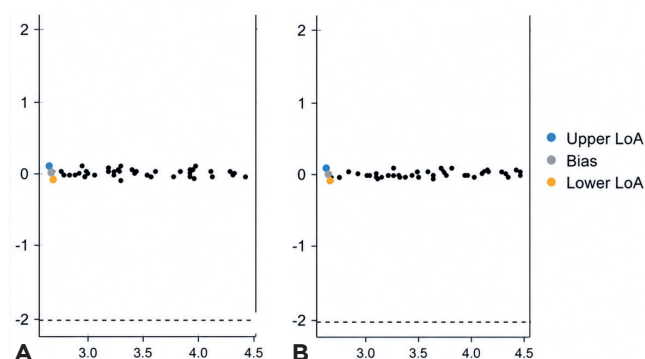


Figure 5. Bland-Altman plots showing agreement between test and retest for the Van Dijk-Asaumi method on the right (A) and left (B) feet.

the method could be sensitive to angular changes greater than 0.4°, although this hypothesis has yet to be confirmed in studies with patients with progressive deformities. This potential is clinically relevant both for the evolutionary follow-up of deformities and for the evaluation of response to therapeutic interventions, filling a need pointed out in studies that compare clinical and imaging evaluations⁽¹⁷⁾.

An apparent discrepancy between the moderate ICC (0.54–0.61) and the near-perfect Lin coefficient (0.996–0.997) can be explained by the distinct nature of these indices. The ICC is sensitive to systematic variability among raters, as present in our intentionally heterogeneous sample (residents and specialists). The Lin coefficient and the Bland-Altman analysis evaluated the pairwise agreement and temporal stability, which were adequate under standardized conditions. Therefore, the results are not contradictory, but complementary.

Another important aspect is that the analysis included raters with different levels of experience. The fact that excellent temporal stability was maintained regardless of the evaluator reinforces the method's applicability across heterogeneous teaching and clinical practice environments. In the literature, reliability studies in foot and ankle radiology often highlight the evaluator's experience as a critical factor for reproducibility⁽¹⁸⁾. In this context, our results are promising, suggesting that with a well-defined protocol and standardized basic training, the adapted Van Dijk-Asaumi method can be safely incorporated into clinical routine and resident training, mitigating the variability traditionally associated with the learning curve and facilitating its wider adoption.

In summary, the adapted Van Dijk-Asaumi method proved to be a radiographic technique with excellent temporal stability,

low measurement error, and high test-retest agreement. Its simplicity and robust performance, even among evaluators with different experience, make it a practical and promising alternative for the quantitative evaluation of hindfoot coronal alignment in clinical practice and future research.

We recognize as main limitations of this study the exclusive inclusion of individuals without apparent clinical or radiographic deformities, which limits the clinical validity of the method in populations with deformities; the modest sample size and sample homogeneity, which restrict the generalization of the findings; the only moderate interobserver reliability, which, although compatible with other radiographic methods, indicates that the method is not exempt from interrater variability; the absence of direct comparison with established methods (Van Dijk original, Saltzman, WBCT) in the same study, which prevents a definitive conclusion on superiority or equivalence; the impossibility of affirming, based on current data, sensitivity to detect subtle clinical changes over time, once progressive. Future studies with clinical samples, including patients with varus and valgus deformities, are needed to validate the method under these conditions and determine its diagnostic accuracy.

Conclusion

The adapted Van Dijk-Asaumi method demonstrated adequate temporal stability and low measurement error, but only moderate interobserver reliability. Although the results are promising, clinical validation in populations with deformities is still required before recommendation for widespread clinical use. The method is currently configured as a technical alternative for future studies and for use in resource-limited contexts, provided that its limitations are recognized.

Authors' contributions: Each author contributed individually and significantly to the development of this article: ISMC *(<https://orcid.org/0000-0002-6183-6667>) Conceived and planned the activities that led to the study, interpreted the results of the study, formatting of the article, and wrote the article; DLT *(<https://orcid.org/0000-0001-9024-2553>), RPL *(<https://orcid.org/0009-0002-4246-5538>), MMS *(<https://orcid.org/0009-0006-9079-6496>), LFM *(<https://orcid.org/0000-0003-0318-2842>) Data collection, statistical analysis, and wrote the article; IDA *(<https://orcid.org/0000-0002-4074-0412>) Participated in the review process and supervision. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) 

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Original Article

Epidemiology and mechanisms of tennis-related ankle and foot injuries presenting to United States emergency departments: A 10-year national analysis (2015-2024)

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Abstract

Objective: To characterize the epidemiology, demographics, diagnoses, mechanisms of injury, and temporal trends of tennis-related ankle and foot injuries presenting to United States emergency departments between 2015 and 2024.

Methods: This descriptive epidemiology study used the National Electronic Injury Surveillance System database to identify tennis-related ankle, foot, and toe injuries presenting to United States emergency departments from January 1, 2015, through December 31, 2024. Demographic characteristics, injury diagnoses, body-part involvement, injury location, disposition, narrative mechanism, and temporal trends were analyzed. National estimates were calculated using NEISS sample weights, and approximate 95% confidence intervals were calculated for key proportions to contextualize estimate stability.

Results: A total of 616 unweighted cases met inclusion criteria, corresponding to an estimated 22,497 emergency-department presentations nationally. Females accounted for 53.1% of injuries, while males accounted for 46.9%. The most affected age groups were 20-44 years (32.5%) and 14-19 years (31.0%). The ankle represented the most frequently injured body part, accounting for 73.1% of injuries. Sprains and strains were the most common diagnosis (63.2%), with ankle sprains/strains comprising the largest single diagnosis-body part combination (53.9%). Acute non-fall, non-contact injuries represented the predominant mechanism (74.2%). Most injuries occurred at sports and recreation facilities (77.6%), and 98.7% of patients were treated and released from the emergency department. No statistically significant temporal trends were observed across age groups.

Conclusion: Tennis-related ankle and foot injuries presenting to United States emergency departments are predominantly ankle sprains sustained through acute non-contact mechanisms. These findings should be interpreted as a descriptive estimate of emergency-department burden rather than sport-wide incidence. Tennis-specific prevention programs emphasizing neuromuscular control, balance training, proprioception, and ankle stabilization may help reduce injury burden among tennis players.

Level of Evidence III; Retrospective Descriptive Epidemiological Study.

Keywords: Tennis; Ankle injuries; Foot injuries; Sports medicine; Epidemiology.

Study performed at Icahn School of Medicine at Mount Sinai, New York, NY, USA.

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Introduction

Tennis is one of the most widely played individual sports worldwide and requires repeated acceleration, deceleration, cutting, pivoting, lunging, and rapid changes in direction. In the United States, tennis participation has increased substantially in recent years, reaching 27.3 million players in 2025 after six consecutive years of growth⁽¹⁾. These demands place substantial biomechanical stress on the musculoskeletal system, particularly the lower extremity. Previous epidemiologic reviews have demonstrated that lower extremity injuries account for a substantial proportion of tennis-related injuries, and ankle injuries are frequently identified among the most common acute injuries in tennis players^(2–4).

Prior authors have emphasized that the incidence, severity, and location of tennis injuries vary across study populations because of differences in injury definitions, surveillance methods, athlete level, and exposure measurement⁽⁵⁾. While broad tennis injury epidemiology has been described, many studies focus on professional, collegiate, or junior athletes rather than national emergency department presentations. A prior National Electronic Injury Surveillance System (NEISS) analysis of tennis-related sprains and strains reported that ankle sprains/strains represented the most common sprain/strain location, but more contemporary data focused specifically on ankle-foot injuries remain limited⁽⁶⁾. Emergency department-based surveillance is clinically useful because it captures acute injuries severe enough to prompt emergency evaluation across a national sample, including recreational players and athletes outside organized surveillance systems.

Adolescent and young adult tennis players represent a particularly important group for injury surveillance. Prospective studies of junior tennis players have identified ankle sprains among common acute injuries, and collegiate surveillance data have shown that lower extremity injuries account for a large proportion of tennis injuries in both men and women^(7–10). Recent Grand Slam tournament surveillance has similarly demonstrated a meaningful burden of ankle and foot injuries among elite tennis players^(11,12).

Ankle sprains are among the most common sports-related injuries and may result in recurrent injury, persistent symptoms, chronic ankle instability, and long-term functional limitations^(13–17). This is clinically relevant in tennis because the sport requires repeated lateral shuffling, abrupt stopping, pivoting, and lunging, all of which can place the ankle in positions vulnerable to inversion injury or loss of neuromuscular control.

Understanding the mechanisms of tennis-related ankle-foot injuries is important because many non-contact injuries may be modifiable. Prior evidence supports the use of neuromuscular training, proprioceptive exercise, balance training, and external ankle support to reduce ankle sprain incidence or recurrence in athletic populations^(18–23). Identifying the demographic groups, diagnoses, body parts, and mechanisms associated with the greatest injury burden

may therefore help guide prevention strategies in tennis players.

The objective of this study was to characterize the epidemiology, demographics, diagnoses, mechanisms of injury, and temporal trends of tennis-related ankle and foot injuries presenting to United States emergency departments from 2015 through 2024 using the NEISS database. We hypothesized that tennis-related ankle and foot injuries would disproportionately affect adolescent and young adult athletes, most commonly involve the ankle, predominantly consist of sprains and strains, and most frequently result from acute non-contact mechanisms.

Methods

Data collection

All data used in the current study were obtained from the NEISS database, a publicly available injury surveillance system maintained by the United States Consumer Product Safety Commission. NEISS collects injury data from a nationally representative probability sample of hospitals in the United States and its territories and provides information on emergency department visits associated with consumer products, sports, and recreational activities⁽²⁴⁾. NEISS case weights were applied to generate national estimates. Because this study was designed as a descriptive epidemiologic analysis, weighted projections were interpreted as estimates of emergency-department burden rather than exact national injury counts.

Case selection

The NEISS database was queried for tennis-related ankle and foot injuries treated between January 1, 2015 and December 31, 2024 using the most recent 10-year study period. Cases were identified using the tennis product code in combination with body-part codes corresponding to the ankle, foot, and toe. Injury narratives were reviewed to confirm tennis-related injury and classify mechanism of injury. Cases without evidence of tennis participation or without ankle-foot involvement were excluded. A small number of records with body-part codes outside the ankle, foot, or toe categories were retained only when the narrative explicitly described ankle or foot involvement; these were preserved as “other coded cases” to maintain transparency rather than recoding the original NEISS body-part field.

Variables

Variables collected included year of treatment, age, sex, race, diagnosis, body part injured, injury location, disposition, and narrative mechanism. Age was categorized into 0–13, 14–19, 20–44, 45–64, 65–84, and ≥ 85 years. Race categories included White, Black/African American, Asian, Native Hawaiian/Pacific Islander, Other, and Not specified. Disposition categories included treated and released, admitted or hospitalized, held for observation, and other outcomes.

Classification of mechanisms

Injury narratives were reviewed and categorized according to a structured mechanism classification system. Mechanisms included acute non-fall, non-contact injury; non-contact trip/fall injury; overuse or repetitive strain; equipment-related injury; contact trip/fall; acute contact non-fall; and unknown or insufficient detail. A reproducible hierarchical algorithm was used: narratives describing direct player or object contact were classified as acute contact injuries; narratives describing slipping, tripping, poor footing, or falling without direct contact were classified as non-contact trip/fall injuries; narratives describing stepping on a tennis ball, being struck by equipment, or court-related structures were classified as equipment-related injuries; narratives describing gradual onset, repetitive activity, or overuse were classified as overuse/repetitive strain; narratives describing sudden twisting, cutting, pivoting, abrupt stopping, acceleration, deceleration, push-off, or inversion without a fall or contact were classified as acute non-fall, non-contact injuries; and narratives lacking sufficient detail were classified as unknown/insufficient detail. Two independent reviews of the injury narratives were performed using these prespecified rules. Disagreements were resolved by consensus review, and inter-rater reliability for the initial mechanism classification was assessed using Cohen's kappa.

Statistical analysis

Descriptive statistics were used to summarize injury distributions. Frequencies, percentages, and national estimates were calculated for demographics, diagnoses, body-part involvement, mechanisms, injury locations, and dispositions. National estimates were generated using NEISS sample weights, and percentages were calculated from weighted estimates. Approximate 95% confidence intervals for selected key proportions were calculated using Wilson score intervals based on unweighted case counts; approximate national-estimate intervals were generated by applying these proportional intervals to the total weighted estimate. These intervals were used to contextualize precision and estimate stability, not as formal design-based variance estimates. Complex survey variance estimation was not performed, and estimates based on small unweighted cell counts, particularly fewer than 20 cases, were interpreted cautiously. Inter-rater reliability for mechanism classification was assessed using unweighted Cohen's kappa with a bootstrap 95% confidence interval. Sex-stratified distributions were additionally calculated for mechanism of injury, year of presentation, body-part involvement, and diagnosis. Temporal trends were evaluated using simple linear regression analysis of annual national estimates across age groups. This trend analysis was considered exploratory because weighted annual estimates and subgroup counts may be unstable when based on small numbers. Statistical significance was defined as $p < 0.05$.

Results

Overall injury burden

Between January 1, 2015 and December 31, 2024, a total of 616 unweighted tennis-related ankle and foot injury cases met inclusion criteria within the NEISS database. These cases corresponded to an estimated 22,497 injuries presenting to United States emergency departments during the study period. This value represents a weighted national projection and should not be interpreted as an exact count of all tennis-related ankle-foot injuries in the United States.

Demographic characteristics

Females accounted for 53.1% of all injuries ($n = 11,942$ national estimate; approximate 95% CI, 49.2%-57.0%), while males accounted for 46.9% ($n = 10,555$ national estimate; approximate 95% CI, 43.0%-50.8%). The largest injury burden was observed among individuals aged 20-44 years (32.5%; approximate 95% CI, 28.9%-36.3%), followed by those aged 14-19 years (31.0%; approximate 95% CI, 27.5%-34.8%). Together, these age groups accounted for nearly two-thirds of all injuries. Detailed demographic characteristics are presented in Table 1, and age distributions are illustrated in Figure 1. Additional approximate confidence intervals for key estimates are shown in Table 2.

Body part distribution

The ankle was the most frequently injured body part, accounting for 73.1% of all injuries ($n = 16,434$; approximate

Table 1. Demographic characteristics of tennis-related ankle and foot injuries presenting to United States emergency departments, 2015-2024

Variable	Cases	National estimate	Percentage
Sex			
Female	327	11,942	53.1
Male	289	10,555	46.9
Age group			
0-13	74	2,703	12.0
14-19	191	6,975	31.0
20-44	200	7,304	32.5
45-64	112	4,090	18.2
65-84	37	1,351	6.0
≥ 85	2	73	0.3
Race			
Not specified	227	8,290	36.8
White	271	9,897	44.0
Black/African American	54	1,972	8.8
Asian	43	1,570	7.0
Other	18	657	2.9
Native Hawaiian/Pacific Islander	1	37	0.2

95% CI, 69.5%-76.4%), followed by the foot (22.4%, $n = 5,040$; approximate 95% CI, 19.3%-25.9%) and toe (3.6%, $n = 803$; approximate 95% CI, 2.4%-5.3%) (Table 3, Figure 2). Sex-stratified body-part distributions were similar: ankle injuries predominated among both males (203 cases; national estimate, 7,414; 70.2%) and females (247 cases; national estimate, 9,021; 75.5%), followed by foot injuries among males (71 cases; national estimate, 2,593; 24.6%) and females (67 cases; national estimate, 2,447; 20.5%) (Table 4).

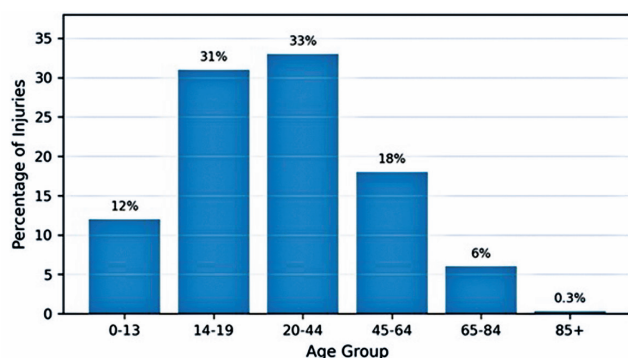


Figure 1. Age distribution of tennis-related ankle and foot injuries presenting to United States emergency departments from 2015 through 2024.

Diagnosis distribution

Sprains and strains represented the most common diagnosis overall, accounting for an estimated 14,207 injuries nationally (63.2%; approximate 95% CI, 59.3%-66.9%) (Table 5, Figure 3). By body part, ankle sprains/strains represented the largest single diagnosis-body part combination, accounting for 12,125 injuries (53.9% of total injuries). Foot sprains/strains accounted for 1,972 injuries (8.8%), whereas toe sprains/strains accounted for 73 injuries (0.3%). Fractures represented the second most common discrete diagnosis overall (14.8%; approximate 95% CI, 12.2%-17.8%), with ankle fractures accounting for 1,826 injuries (8.1%), foot fractures accounting for 1,278 injuries (5.7%), and toe fractures accounting for 110 injuries (0.5%). The “other/not stated” category accounted for 18.2% of injuries and primarily reflects NEISS diagnosis entries in which the available code or narrative did not specify a discrete diagnosis beyond pain, swelling, nonspecific injury, or otherwise uncategorized clinical assessment. Diagnosis distributions stratified by body part are shown in Table 6. Among ankle sprains/strains specifically, females accounted for 185 cases and an estimated 6,756 injuries nationally (56.0%), whereas males accounted for 147 cases and an estimated 5,369 injuries nationally (44.0%) (Table 7). Sex-stratified diagnosis patterns were also similar overall, with sprains/strains representing the leading diagnosis in both

Table 2. Key national estimates and approximate 95% confidence intervals

Category	Cases	National estimate	Approximate national estimate 95% CI	Percentage, % (95% CI)
Female	327	11,942	11,054-12,822	53.1 (49.1-57.0)
Male	289	10,555	9,675-11,443	46.9 (43.0-50.9)
Age 14-19 years	191	6,975	6,182-7,822	31.0 (27.5-34.8)
Age 20-44 years	200	7,304	6,499-8,158	32.5 (28.9-36.3)
Ankle injuries	450	16,434	15,616-17,189	73.1 (69.4-76.4)
Foot injuries	138	5,040	4,339-5,818	22.4 (19.3-25.9)
Toe injuries	22	803	533-1,203	3.6 (2.4-5.3)
Sprain/strain	389	14,207	13,334-15,043	63.1 (59.3-66.9)
Fracture	91	3,323	2,742-4,003	14.8 (12.2-17.8)
Acute non-fall, non-contact mechanism	457	16,690	15,881-17,432	74.2 (70.6-77.5)
Non-contact trip/fall	61	2,228	1,752-2,816	9.9 (7.8-12.5)
Sports/recreation facility	478	17,457	16,679-18,158	77.6 (74.1-80.7)
Treated and released	608	22,205	21,925-22,349	98.7 (97.5-99.3)

Note: Confidence intervals are approximate Wilson score intervals based on unweighted case counts and scaled to the total weighted estimate; they are intended to contextualize precision rather than replace design-based survey variance estimates.

Table 3. Distribution of injuries by body part

Body part	Cases	National estimate	Percentage
Ankle	450	16,434	73.0
Foot	138	5,040	22.4
Toe	22	803	3.6
Other lower/upper extremity or trunk coded cases	6	219	1.0
Total	616	22,497	100.0

males (172 cases; national estimate, 6,282; 59.5%) and females (217 cases; national estimate, 7,925; 66.4%) (Table 8).

Mechanism of injury

Acute non-fall, non-contact injuries represented the predominant mechanism of injury, accounting for 74.2% of all injuries and an estimated 16,690 injuries nationally (approximate 95% CI, 70.6%-77.5%). Non-contact trip/fall injuries represented the second most common mechanism (9.9%), followed by overuse/repetitive strain (6.0%) and equipment-related injury (5.8%) (Table 9, Figure 4). Among ankle injuries, acute non-contact mechanisms accounted for

365 of 450 ankle injury cases, representing approximately 81.1% of ankle injuries. Among foot injuries, acute non-contact mechanisms accounted for 85 of 138 cases (61.6%), followed by overuse/repetitive strain (21 of 138 cases; 15.2%) and non-contact trip/fall injuries (14 of 138 cases; 10.1%). Among toe injuries, acute contact non-fall mechanisms accounted for 7 of 22 cases (31.8%), with acute non-contact and overuse/repetitive strain mechanisms each accounting for 4 of 22 cases (18.2%) (Table 10). Initial agreement between reviewers for mechanism classification was 91.9% (566 of 616 cases), with a Cohen's kappa of 0.82 (bootstrap 95% CI, 0.77-0.87), indicating strong inter-rater reliability.

Sex-stratified injury patterns

Sex-stratified mechanism distributions showed that acute non-fall, non-contact injury was the leading mechanism among both males (217 cases; national estimate, 7,925; 75.1%) and females (240 cases; national estimate, 8,765; 73.4%). Females had a higher proportion of non-contact trip/fall injuries (12.5% vs 6.9%) and equipment-related injuries (8.0% vs 3.5%), whereas males had a higher proportion of overuse/repetitive strain injuries (8.7% vs 3.7%) (Table 11). Annual sex-stratified estimates are presented in Table 12; females had higher national estimates in most years, estimates were equal in 2020, and males had higher estimates in 2015 and 2023.

Location of injury

Most injuries occurred at sports and recreation facilities, which supports the face validity of the dataset and suggests

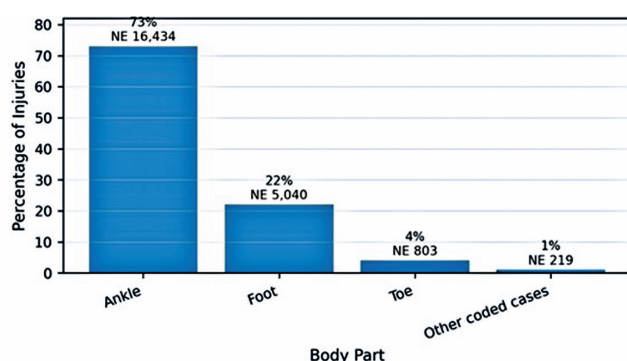


Figure 2. Distribution of tennis-related ankle and foot injuries by body part.
NE: National estimate.

Table 4. Sex distribution by body part

Body part	Male cases	Male NE	Male %	Female cases	Female NE	Female %
Ankle	203	7,414	70.2	247	9,021	75.5
Foot	71	2,593	24.6	67	2,447	20.5
Toe	12	438	4.2	10	365	3.1
Other coded cases	3	110	1.0	3	110	0.9
Total	289	10,555	100.0	327	11,942	100.0

NE: National estimate.

Table 5. Diagnosis distribution of tennis-related ankle and foot injuries

Diagnosis	Cases	National estimate	Percentage
Sprain/strain	389	14,207	63.2
Other/not stated	112	4,090	18.2
Fracture	91	3,323	14.8
Contusion/abrasion	13	475	2.1
Dislocation	6	219	1.0
Laceration	2	73	0.3
Hematoma	2	73	0.3
Avulsion	1	37	0.2
Total	616	22,497	100.0

that prevention efforts should be directed toward tennis-specific environments. Court-based warm-up programs, balance training, and ankle neuromuscular control exercises could be incorporated into tennis clubs, school programs, recreational leagues, and competitive training settings. Such interventions are particularly relevant because most injuries in this cohort were non-contact and therefore potentially modifiable, although this study cannot directly prove that any specific intervention would reduce emergency-department presentations (Table 13).

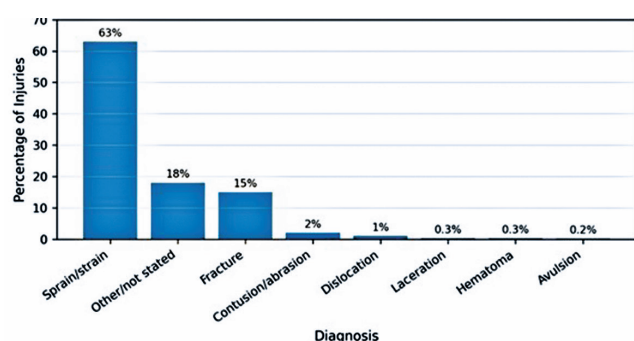


Figure 3. Diagnosis distribution of tennis-related ankle and foot injuries.

Table 6. Diagnosis distribution stratified by body part

Body part	Diagnosis	Cases	National estimate	Percentage of total
Ankle	Sprain/strain	332	12,125	53.9
Ankle	Other/not stated	63	2,301	10.2
Ankle	Fracture	50	1,826	8.1
Ankle	Dislocation	3	110	0.5
Ankle	Contusion/abrasion	1	37	0.2
Ankle	Laceration	1	37	0.2
Foot	Sprain/strain	54	1,972	8.8
Foot	Other/not stated	38	1,388	6.2
Foot	Fracture	35	1,278	5.7
Foot	Contusion/abrasion	9	329	1.5
Toe	Other/not stated	10	365	1.6
Toe	Fracture	3	110	0.5
Toe	Contusion/abrasion	2	73	0.3
Toe	Dislocation	2	73	0.3
Toe	Hematoma	2	73	0.3
Toe	Sprain/strain	2	73	0.3
Toe	Avulsion	1	37	0.2

Table 7. Sex distribution of tennis-related ankle sprains/strains

Ankle sprains/strains	Cases	National estimate	Percentage of total
Male	147	5,369	44.3
Female	185	6,756	55.7
Total	332	12,125	100.0

Disposition

Most patients were treated and released from the emergency department. Treated-and-released dispositions accounted for 98.7% of all injuries (n = 22,205). Hospital admission, observation, and other dispositions collectively accounted for less than 2% of injuries (Table 14).

Table 8. Sex distribution by diagnosis

Diagnosis	Male Cases	Male NE	Male %	Female Cases	Female NE	Female %
Sprain/strain	172	6,282	59.5	217	7,925	66.4
Other/not stated	63	2,301	21.8	49	1,790	15.0
Fracture	38	1,388	13.1	53	1,936	16.2
Contusion/abrasion	8	292	2.8	5	183	1.5
Dislocation	6	219	2.1	0	0	0.0
Laceration	1	37	0.3	1	37	0.3
Hematoma	0	0	0.0	2	73	0.6
Avulsion	1	37	0.3	0	0	0.0
Total	289	10,555	100.0	327	11,942	100.0

Table 9. Mechanism of injury distribution

Mechanism	Cases	National estimate	Percentage
Acute non-fall, non-contact injury	457	16,690	74.2
Non-contact trip/fall	61	2,228	9.9
Overuse/repetitive strain	37	1,351	6.0
Equipment-related injury	36	1,315	5.8
Unknown/insufficient detail	11	402	1.8
Acute contact non-fall	8	292	1.3
Contact trip/fall	6	219	1.0
Total	616	22,497	100.0

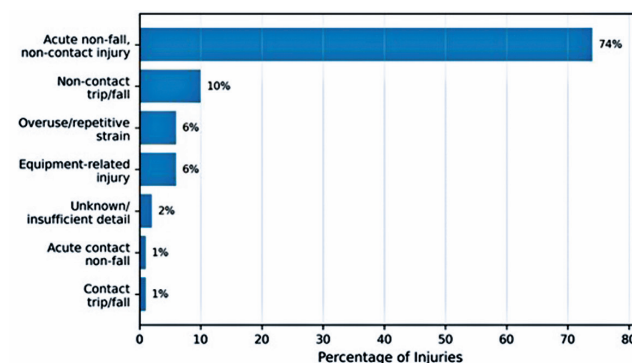


Figure 4. Mechanism of injury distribution among tennis-related ankle and foot injuries.

Temporal trends

Annual national estimates of tennis-related ankle and foot injuries fluctuated over the 10-year study period, with a lower estimate observed in 2020 and a return toward pre-2020 estimates in subsequent years (Figure 5). Linear regression analysis demonstrated no statistically significant temporal trends across age groups during the study period. Adults aged 65-84 years demonstrated the strongest positive coefficient (beta = 23.24 injuries per year; $p = 0.065$), but this did not reach statistical significance and should be interpreted only as a hypothesis-generating pattern. No significant trends were observed among individuals aged 0-13 years ($p = 0.379$), 14-19 years ($p = 0.855$), 20-44 years ($p = 0.401$), 45-64 years ($p = 0.684$), or ≤ 85 years ($p = 1.000$) (Table 15, Figure 6).

Discussion

This study provides a contemporary national analysis of tennis-related ankle and foot injuries presenting to United States emergency departments between 2015 and 2024. The primary novelty of this study is its specific focus on the ankle-foot complex over a recent 10-year period, with narrative-based mechanism classification, body-part stratification, sex-stratified analyses, and emergency department-based national estimates. This differs from prior studies that evaluated overall tennis injuries, selected competitive athlete cohorts, or tennis-related sprains and strains more broadly. Several important findings emerged. First, ankle injuries accounted for nearly three-quarters of all tennis-related ankle and foot injuries. Second, sprains and strains represented the predominant diagnosis, driven primarily by ankle sprains/

Table 10. Mechanism of injury stratified by body part

Body part	Mechanism	Cases	National estimate	Percentage of total
Ankle	Acute non-contact	365	13,330	59.3
Ankle	Non-contact trip/fall	41	1,497	6.7
Ankle	Equipment-related injury	24	877	3.9
Ankle	Overuse/repetitive strain	12	438	1.9
Ankle	Contact trip/fall	4	146	0.6
Ankle	Unknown/insufficient detail	3	110	0.5
Ankle	Acute contact non-fall	1	37	0.2
Foot	Acute non-contact	85	3,104	13.8
Foot	Overuse/repetitive strain	21	767	3.4
Foot	Non-contact trip/fall	14	511	2.3
Foot	Equipment-related injury	10	365	1.6
Foot	Unknown/insufficient detail	6	219	1
Foot	Contact trip/fall	2	73	0.3
Toe	Acute contact non-fall	7	256	1.1
Toe	Acute non-contact	4	146	0.6
Toe	Overuse/repetitive strain	4	146	0.6
Toe	Non-contact trip/fall	3	110	0.5
Toe	Equipment-related injury	2	73	0.3
Toe	Unknown/insufficient detail	2	73	0.3

Table 11. Sex distribution of mechanism of injury

Mechanism	Male cases	Male NE	Male %	Female cases	Female NE	Female %
Acute non-fall, non-contact injury	217	7,925	75.1	240	8,765	73.4
Non-contact trip/fall	20	730	6.9	41	1,497	12.5
Overuse/repetitive strain	25	913	8.7	12	438	3.7
Equipment-related injury	10	365	3.5	26	950	8.0
Unknown/insufficient detail	7	256	2.4	4	146	1.2
Acute contact non-fall	6	219	2.1	2	73	0.6
Contact trip/fall	4	146	1.4	2	73	0.6
Total	289	10,555	100.0	327	11,942	100.0

NE: National estimate.

strains. Third, acute non-fall, non-contact mechanisms accounted for most injuries. Finally, adolescents and young adults experienced the highest injury burden. Collectively, these findings provide descriptive insight into the emergency-department burden of ankle and foot injuries in tennis players and may help generate hypotheses for future prevention studies.

One of the most notable findings was the predominance of ankle injuries. The ankle accounted for 73.1% of all tennis-related ankle-foot injuries presenting to emergency departments. This finding is consistent with prior tennis injury literature showing that lower extremity injuries represent a substantial proportion of tennis injuries and that acute ankle injuries are common among tennis players⁽²⁻⁴⁾. The high proportion of ankle injuries may reflect the movement

demands of tennis, including rapid changes in direction, explosive acceleration, sudden deceleration, and repeated lateral movements. However, this explanation is speculative

Table 12. Sex distribution by year

Year	Male cases	Male NE	Female cases	Female NE
2015	31	1,132	29	1,059
2016	29	1,059	38	1,388
2017	27	986	42	1,534
2018	26	950	38	1,388
2019	33	1,205	37	1,351
2020	22	803	22	803
2021	26	950	30	1,096
2022	26	950	30	1,096
2023	37	1,351	28	1,023
2024	32	1,169	33	1,205
Total	289	10,555	327	11,942

NE: National estimate.

Table 13. Location of injury

Location	Cases	National estimate	Percentage
Sports/recreation facility	478	17,457	77.6
Unknown/not specified	89	3,250	14.4
School	30	1,096	4.9
Home	15	548	2.4
Public property	4	146	0.6
Total	616	22,497	100.0

Table 14. Emergency department disposition

Disposition	Cases	National estimate	Percentage
Treated and released	608	22,205	98.7
Admitted/hospitalized	4	146	0.6
Held for observation	3	110	0.5
Left without being seen/other	1	37	0.2
Total	616	22,497	100.0



Figure 5. Annual national estimates of tennis-related ankle and foot injuries presenting to United States emergency departments from 2015 through 2024.

Table 15. Temporal trends by age group

Age group	Beta coefficient	p-value
0-13	-11.95	0.379
14-19	-4.65	0.855
20-44	-10.18	0.401
45-64	-3.76	0.684
65-84	23.24	0.065
≤ 85	0.00	1.000

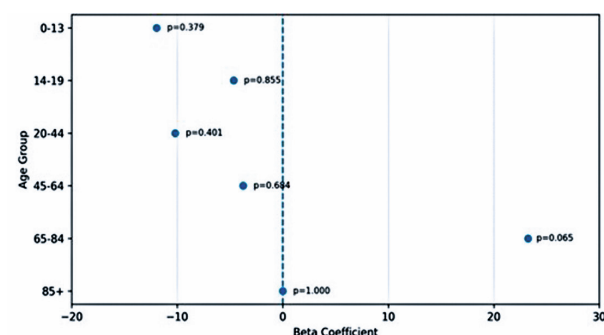


Figure 6. Exploratory temporal trends in tennis-related ankle and foot emergency-department estimates by age group from 2015 through 2024.

Beta coefficients from simple linear regression analyses are displayed for each age group, with positive values indicating increasing annual national estimates and negative values indicating decreasing annual national estimates.

because NEISS does not include exposure, footwear, court surface, or biomechanical data. Therefore, these findings should be interpreted as descriptive and hypothesis-generating rather than causal.

Sprains and strains were the leading diagnosis overall and were especially common at the ankle. This finding aligns with prior NEISS-based work by Chevinsky et al.⁽⁶⁾, who reported that tennis-related sprains and strains represented a meaningful injury burden and that ankle sprains/strains were the most common sprain/strain body part in their study. It also corresponds with prospective junior tennis data identifying ankle sprains among the most frequent injuries in young players^(7,9). Our study extends these findings by specifically evaluating ankle, foot, and toe injuries over a more recent 10-year period and by adding mechanism and body-part stratification.

The predominance of acute non-contact mechanisms is clinically relevant from a prevention standpoint, but causal conclusions cannot be made from these data. Acute non-fall, non-contact injuries accounted for 74.2% of all cases and more than 80% of ankle injury cases. This mechanism category included sudden twisting, cutting, pivoting, abrupt stopping, push-off, and inversion-type injuries. These patterns are consistent with the movement demands of tennis, which repeatedly place players into rapid multiplanar movement and loading positions; however, the present study cannot determine whether specific movements caused injury because exposure-level and biomechanical data were unavailable. Prior studies of sports-related ankle injuries have demonstrated that non-contact mechanisms are common and clinically relevant, particularly in sports requiring cutting, pivoting, jumping, and rapid changes in direction^(13,17).

Tennis-specific factors not captured by NEISS may also influence ankle-foot injury mechanisms. Open-stance and closed-stance hitting positions, split-step timing, lateral recovery steps, abrupt deceleration, and lunging patterns may alter ankle loading during play. Court surface may also matter; hard courts, clay courts, and grass courts differ in traction and sliding characteristics, which may affect the balance between grip, rotational load, and fall risk. Footwear, ankle bracing, prior ankle sprain history, conditioning, and playing level may further modify risk. Recreational players may have different movement efficiency, training volume, and access to prevention programs than collegiate, elite junior, or professional players. Because these variables are not available in NEISS, future prospective tennis-specific studies should evaluate court surface, footwear, stance mechanics, exposure time, and competitive level.

The age distribution observed in this study was also clinically important. Individuals aged 14-19 years and 20-44 years accounted for nearly two-thirds of all injuries. These findings are consistent with prior tennis injury surveillance studies in junior and collegiate athletes, which demonstrate a substantially lower extremity injury burden in younger athletes⁽⁷⁻¹⁰⁾. Several factors likely contribute to this pattern, including greater participation exposure, competitive match

frequency, training volume, and higher-intensity movement demands among adolescents and young adults.

Females accounted for a slightly greater proportion of injuries than males in the current cohort. A similar pattern was observed specifically for ankle sprains/strains, with females accounting for 185 cases and an estimated 6,756 injuries nationally (56.0%) compared with 147 cases and an estimated 5,369 injuries nationally (44.0%) among males. However, the broader sex-stratified tables demonstrated that the main injury pattern was consistent between sexes: ankle injuries, sprains/strains, and acute non-fall, non-contact mechanisms predominated among both males and females. Females demonstrated slightly higher proportions of non-contact trip/fall and equipment-related injuries, whereas males demonstrated a higher proportion of overuse/repetitive strain injuries. These differences should be interpreted cautiously and should not be considered evidence of sex-specific risk because NEISS does not provide participation denominators, match exposure, training volume, or healthcare utilization data. Future sex-stratified analyses should evaluate whether ankle sprain burden, fracture burden, and non-contact mechanisms differ meaningfully between male and female tennis players when exposure data are available.

Although no age group demonstrated a statistically significant temporal trend, adults aged 65-84 years exhibited the strongest positive coefficient and approached, but did not reach, statistical significance. This finding should be interpreted cautiously as a nonsignificant exploratory pattern rather than a true increase. Tennis is often promoted as a lifetime sport because it offers cardiovascular, musculoskeletal, and social benefits. Increased participation among older adults could increase injury exposure in this population, but exposure denominators are necessary to distinguish true risk from participation volume. Older athletes may also have age-related changes in balance, proprioception, tendon quality, bone density, and recovery capacity that influence ankle-foot injury patterns. Future research should evaluate older tennis players specifically and should incorporate participation exposure to distinguish true risk from increased participation volume.

Most injuries occurred at sports and recreation facilities, which supports the validity of the dataset and indicates that prevention efforts should be directed toward tennis-specific environments. Court-based warm-up programs, balance training, and ankle neuromuscular control exercises could be incorporated into tennis clubs, school programs, recreational leagues, and competitive training settings. Such interventions are particularly relevant because most injuries in this cohort were non-contact and therefore potentially modifiable.

Although nearly all patients were treated and released from the emergency department, these injuries should not be dismissed as minor. Emergency-department data provide a distinct view of injuries that are acute or concerning enough to prompt emergency evaluation, complementing athlete surveillance studies, outpatient clinic series, and tournament-based datasets. These data do not capture the full spectrum

of tennis injuries, but they are useful for identifying national patterns in more acute presentations across recreational and competitive settings. Ankle sprains can lead to recurrent injury, chronic ankle instability, persistent pain, activity limitation, and long-term functional impairment^(14–16). The high treated-and-released rate suggests low acute hospitalization burden, but emergency department disposition does not capture downstream morbidity, time lost from sport, rehabilitation needs, or recurrence risk.

The prevention implications of these findings are best viewed as practical and hypothesis-generating rather than definitive. Clinical practice guidelines for lateral ankle ligament sprains emphasize appropriate diagnosis, functional assessment, therapeutic exercise, balance training, and return-to-activity progression⁽¹⁸⁾. Systematic reviews have demonstrated that neuromuscular training, proprioceptive training, bracing, and balance training can reduce ankle sprain incidence or recurrence in athletic populations^(19–23). Given that acute non-contact ankle injuries dominated the current cohort, tennis-specific prevention programs emphasizing single-leg balance, dynamic stability, lateral movement control, landing mechanics, agility technique, and ankle external support for at-risk players may help reduce injury burden, but prospective tennis-specific trials are needed to confirm effectiveness.

For clinicians treating tennis players, the results of this study emphasize the importance of ankle-focused screening and prevention, particularly in athletes with prior ankle sprain, poor balance, recurrent instability, or high-volume play. Sports medicine physicians, foot and ankle surgeons, podiatrists, physical therapists, and athletic trainers should recognize that tennis-related ankle-foot emergency department visits are most commonly ankle sprains occurring through acute non-contact mechanisms. Early evidence-based rehabilitation and structured return-to-play decision-making may help reduce recurrence and chronic ankle instability.

This study has several limitations. First, NEISS captures injuries presenting to emergency departments and does not include injuries managed in outpatient clinics, urgent care centers, athletic training rooms, or private practices. The true burden of tennis-related ankle and foot injuries is therefore likely underestimated. Second, NEISS is a retrospective database and is subject to coding errors, missing data, inaccurate product attribution, incomplete narratives, and variability in emergency-department documentation.

Third, national estimates are weighted approximations and should not be interpreted as exact counts of injuries occurring nationally. Confidence intervals in this study were approximate and were intended to contextualize precision rather than replace full complex survey variance estimation. Fourth, injury classification depended on narrative descriptions recorded within the NEISS database. Although a prespecified mechanism-classification algorithm was used and inter-rater reliability was strong, the classification system was not externally validated. Incomplete documentation may have resulted in mechanism misclassification, particularly for narratives that did not clearly distinguish pivoting, slipping, equipment involvement, and falling. Fifth, several subgroup estimates, including toe injuries, avulsion injuries, hospital admissions, and observation cases, were based on small unweighted counts and should be interpreted cautiously because NEISS weighted projections can be unstable in sparse cells. Sixth, NEISS does not include exposure data such as hours played, level of competition, playing surface, footwear, prior injury history, training volume, or match participation. As a result, injury rates relative to exposure could not be calculated, and sex-specific differences in injury risk should be interpreted cautiously without participation denominators. Finally, the retrospective descriptive design limits the ability to establish causal relationships between demographic characteristics, injury mechanisms, and outcomes.

Conclusion

Tennis-related ankle and foot injuries represent a meaningful emergency-department burden in the United States. The ankle was the most frequently injured body part, sprains and strains were the predominant diagnosis, and acute non-fall, non-contact mechanisms represented the leading mechanism of injury. Adolescents and young adults experienced the greatest injury burden. No statistically significant temporal trends were observed across age groups, although older adults demonstrated a nonsignificant positive coefficient that warrants further study with exposure data. Given the predominance of non-contact mechanisms, prevention programs emphasizing neuromuscular control, proprioception, balance training, sport-specific agility, and ankle stabilization may help reduce injury occurrence and improve athlete outcomes, but future prospective tennis-specific studies are needed.

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Original Article

Reverdin-Isham modified vs MICA for moderate hallux valgus: A comparative study

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Abstract

Objective: To compare clinical, functional, and radiographic results of the modified minimally invasive Reverdin-Isham (RImod) and minimally invasive Chevron-Akin (MICA) techniques in the treatment of moderate hallux valgus.

Methods: Retrospective comparative study of 81 feet (38 MICA, 43 RImod) with moderate hallux valgus ($\text{IMA} \leq 18^\circ$, $\text{HVA} \leq 40^\circ$). Pre- and postoperative evaluations (6 months) included the AOFAS score, intermetatarsal angles (IMA) and hallux valgus angle (HVA), and fibular sesamoid subluxation (FSS). Statistical analysis used Student's t and Wilcoxon's tests, with adjustment for bilateral testing.

Results: Both groups demonstrated significant improvement ($p < 0.001$) in AOFAS (MICA: 37.9 ± 12.6 to 90.95 ± 8.1 ; RImod: 40.47 ± 13.1 to 93.4 ± 6.5), IMA (MICA: $14.9 \pm 2.1^\circ$ to $10.0 \pm 3.0^\circ$; RImod: $14.4 \pm 2.1^\circ$ to $10.0 \pm 2.8^\circ$), HVA (MICA: $31.3 \pm 6.1^\circ$ to $11.8 \pm 5.7^\circ$; RImod: $29.0 \pm 5.8^\circ$ to $11.0 \pm 4.4^\circ$) and FSS (MICA: 89% to 53%; RImod: 82% to 51%). There was no statistically significant difference between the techniques for functional gain ($p = 0.98$), IMA correction ($p = 0.43$), HVA ($p = 0.30$), or FSS ($p = 0.41$). The complication rate was 21.1% for MICA and 9.3% for RImod ($p = 0.149$), with different profiles: MICA presented problems with implants and recurrence, while RImod had cases of nerve injury and malunion.

Conclusion: RImod and MICA are effective for the correction of moderate hallux valgus, with comparable clinical and radiographic results. Both techniques demonstrated significant clinical and radiographic improvements, with functional gains in AOFAS score and substantial angular corrections in HVA, IMA, and FSS.

Level of Evidence III; Comparative Retrospective Study.

Keywords: Hallux valgus; Minimally invasive surgery; Chevron-Akin; Modified Reverdin-Isham.

Introduction

Hallux valgus (HV) is one of the most prevalent deformities of the forefoot, characterized by lateral deviation of the hallux and medial deviation of the first metatarsal (M1), often associated with pain, calluses, and difficulties in wearing shoes^(1,2). Its etiology is multifactorial, involving genetic, bio-mechanical, and environmental aspects^(1,2). Surgical treatment is indicated for patients refractory to conservative management, aiming to correct the deformity, relieve pain, and improve function⁽¹⁾.

In recent decades, minimally invasive surgery (MIS) of the foot, also known as percutaneous surgery, has emerged as

a promising alternative to traditional open techniques for HV treatment⁽³⁾. Theoretical advantages include less tissue trauma, smaller incisions, less postoperative pain, faster recovery, and shorter surgical time⁽⁴⁾. However, the literature still lacks high-level evidence studies that directly compare different percutaneous techniques^(4,5).

The original Reverdin-Isham technique, described by Isham⁽⁶⁾ as a modification of the Reverdin osteotomy⁽⁶⁾, aims to realign the joint surface and correct the angle. However, instability of the M1 osteotomy is a concern⁽⁷⁾. To address this issue, a modification of the Reverdin-Isham technique, known as Modified Reverdin-Isham (RImod), was described

Study performed at the Hospital Universitário de Taubaté, Taubaté, SP, Brazil.

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in 2021 and incorporates an oblique cut in the neck of M1 with a bony step⁽⁷⁾. This modification aims to provide greater stability to the osteotomy, allowing lateral displacement of the metatarsal head for proper correction of the deformity, without the routine need for internal fixation⁽⁷⁾.

In parallel, the minimally invasive Chevron-Akin (MICA) technique represents an evolution of percutaneous Chevron osteotomy. Originally, Chevron osteotomy described by Austin and Leventen⁽⁸⁾, is a “V” osteotomy on the neck of M1, with lateral displacement of the head. Vernois and Redfern^(4,9) demonstrated the percutaneous Chevron technique with fixation by two screws, increasing stability and allowing greater displacement of the metatarsal head, making it applicable even for more severe deformities⁽⁹⁾.

Given the need for comparative evidence, this retrospective study evaluates patients with moderate HV (intermetatarsal angles (IMA) $\leq 18^\circ$ and hallux valgus angle (HVA) $\leq 40^\circ$)⁽¹⁰⁾, comparing the clinical, functional, and radiographic results of the RImod and MICA techniques, contributing to the understanding of their relative effectiveness and assisting clinical decision-making.

Methods

Study design and context

This is a longitudinal retrospective observational study (before-after) and a comparative study between two groups, conducted through the review of medical records and imaging exams of patients with moderate HV. Patients underwent MIS between 2012 and 2024 in different services.

The study compared the results of RImod and MICA techniques: Potential biases due to inclusion of data from different centers and authorship of the RImod technique will be discussed as limitations.

Eligibility criteria

Patients with moderate HV refractory to conservative treatment, with a minimum postoperative follow-up of six months, were included. The classification of moderate HV was defined by a HVA $\leq 40^\circ$, according to the criteria of Coughlin and Mann⁽¹¹⁾ and IMA $\leq 18^\circ$ in accordance with the criterion adopted by De Prado et al.⁽¹⁰⁾, which establishes this value as the upper limit to indicate distal percutaneous techniques of the M1, an approach also used in Bauer et al.⁽¹²⁾ study.

Patients with previous surgery on the first radius of the foot, peripheral vascular diseases, rheumatological diseases, active infections, acute fractures, or incomplete data that prevented analysis were excluded from the study.

Sample

The final sample consisted of 81 operated feet, divided into two groups:

- MICA group (n = 38 feet):
- MICA only: 15 feet

- MICA + associated procedures at other radius: 23 feet

Of these 23 feet, 19 feet required metatarsal osteotomies (Distal Metatarsal Metaphyseal Osteotomy (DMMO)), and eight feet had smaller toe claws that were realigned.

- RImod group (n = 43 feet):
- RImod + Aikin: 20 feet
- RImod + Aikin + associated procedures at other radius: 23 feet

Of these 23 feet, 20 feet required metatarsal osteotomies (DMMO), 13 had smaller toe claws that were realigned, and one foot had correction of overriding second toe.

Data collection and evaluated variables

Demographic (sex, age, side of the foot operated) and clinical (postoperative complications) data were collected from medical records. Functional and radiographic evaluations were performed preoperatively and in the sixth postoperative month.

The variables evaluated included:

- American Orthopaedic Foot & Ankle Society (AOFAS): functional score that assesses pain, function, and hindfoot, midfoot, and forefoot alignment (0-100 points, where 100 is the best result)⁽¹³⁾.
- The weight-bearing radiographs were performed in anteroposterior (AP) and lateral views. Radiographic measurements were performed by a single evaluator (unblinded), using digital software.
- IMA: measured on weight-bearing AP radiographs (degrees).
- HVA: measured on weight-bearing AP radiographs (degrees).
- Fibular sesamoid subluxation (FSS): evaluated on weight-bearing AP radiographs, according to Coughlin and Mann's classification⁽¹¹⁾. FSS was visually categorized into quartiles and grouped into Grades I, II, and III for analysis.

Surgical procedures

All surgeries were performed by surgeons experienced in MIS techniques.

- MICA group: The MICA technique involved a “V” osteotomy on the neck of the M1, with lateral displacement of the head and fixation with screws, associated with Akin osteotomy (Figure 1).
- RImod group: The RImod technique consisted of an oblique cut in the neck of M1 with a bony step to lateralize the metatarsal head, providing greater stability without the routine need for internal fixation and Akin osteotomy (Figures 2 and 3).

Associated procedures were allowed in both groups and will be considered potential confounding factors in the discussion.

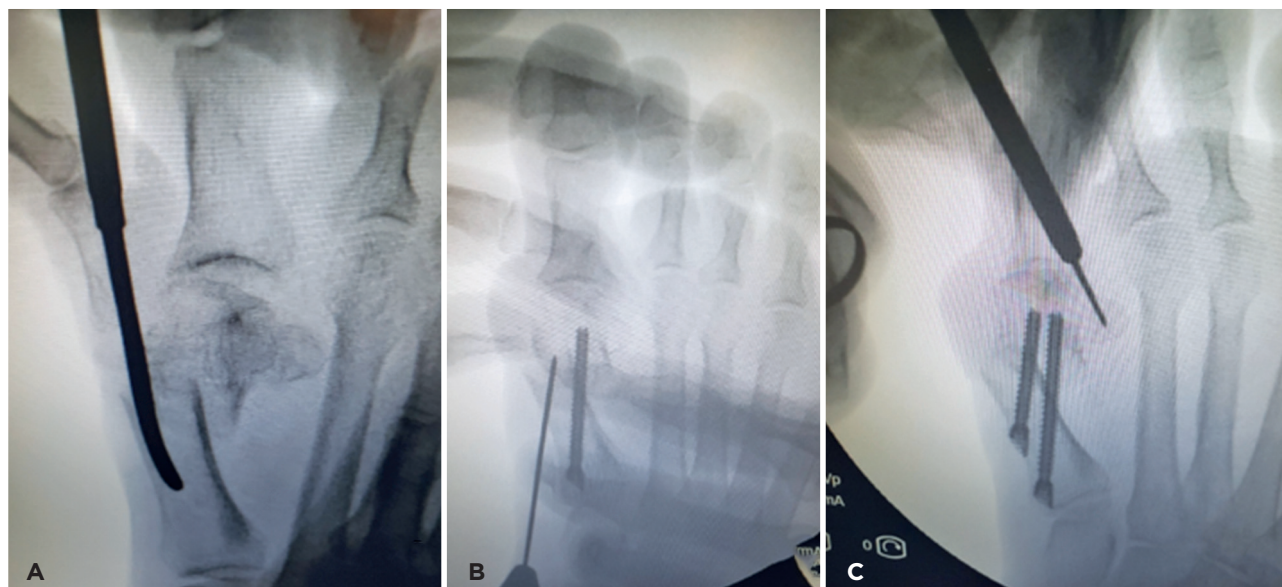


Figure 1. Intraoperative radiographs of the MICA technique. (A) The lateral displacement of the first metatarsal head, (B) the guidewire passage of the second screw, (C) osteotomy already fixed, preparing to perform the tenotomy of the adductor of the hallux.



Figure 2. (A-B) Clinical and radiographic image showing the moderate hallux valgus, (C-D) clinical image and radiography after RImod technique.

Postoperative period

The postoperative protocol included initial immobilization and progressive rehabilitation, with immediate weight-bearing in both techniques.

Weekly dressings were performed at the outpatient clinic for four weeks; thereafter, patients performed their own dressings at home from weeks 4 to 8 in both techniques. During this period, patients were instructed to wear a rigid-sole sandal full time for the first two months.

Control radiographs were performed in the first, fourth, and eighth postoperative weeks.

Statistical analysis

Data were organized and analyzed using Stata software (version 17.0, StataCorp LLC, College Station, TX, USA). Continuous variables were described by mean and standard deviation (SD). The normality of the data distribution was verified by the Shapiro-Wilk test. For preoperative comparisons

between groups, Student's t-test was used for continuous variables with normal distribution, or the Mann-Whitney U test for non-parametric variables. For pre- vs. postoperative comparisons within each group, the paired t-test was used for continuous variables with a normal distribution, or the Wilcoxon test for non-parametric variables. To compare the differences (Δ = post-pre) between the groups, the Student's t-test for independent samples or the Mann-Whitney U test were used. The FSS variable (Grades I-III), being an ordinal categorical variable, was analyzed using non-parametric tests (Wilcoxon for intra-group comparisons and Mann-Whitney U or ordinal regression models for inter-group comparisons). For the bilateral adjustment, inferential estimates were calculated with adjustment for cluster per patient (ID), reducing the risk of overestimation of significance due to non-independence of observations. A significance level of $p < 0.05$ was adopted in all analyses.

Ethical aspects

The study was approved by the Institutional Review Board. As this is a retrospective review, the data were analyzed anonymously, preserving patient confidentiality.

Results

A total of 81 feet with moderate HV (MICA: $n = 38$; RImod: $n = 43$) were evaluated. The sample, composed predominantly of middle-aged and older women, was operated on in different services, with a mean follow-up of 28.1 months (minimum of six months and maximum of more than six years). The mean postoperative follow-up time was 30.3 months in the MICA group and 26.2 months in the RImod group.

Sample characteristics (preoperative data)

The groups had comparable demographic characteristics and preoperative parameters (clinical, functional, and radiographic).

In the MICA group, the preoperative AOFAS score was 37.9 ± 12.6 points, the mean IMA was $14.9 \pm 2.1^\circ$, the HVA was $31.3 \pm 6.1^\circ$, and the FSS of the hallux was estimated at 0.89 ± 0.18 ($\approx 89\%$), a value compatible with severe (Grade III) displacement of the fibular sesamoid. In the RImod group, the preoperative AOFAS was 40.47 ± 13.1 points, the IMA was $14.4 \pm 2.1^\circ$, the HVA was $29.0 \pm 5.8^\circ$, and the mean FSS was 0.82 ± 0.22 ($\approx 82\%$), also within the severe profile.

These data indicate that, although the patients were classified as having moderate HV based on IMA and HVA, from the point of view of the sesamoid position (Coughlin and Mann's criterion⁽¹¹⁾), most of the feet had a radiographic pattern compatible with Grade III (severe) of lateral subluxation (Table 1).

Intragroup comparison (pre- vs postoperative)

In the intragroup analysis (paired sample t-test), a statistically significant improvement was observed in all evaluated parameters – AOFAS, IMA, HVA, and FSS – in both MICA and RImod groups (Table 2).

In the MICA group:

- The AOFAS score increased from 37.9 ± 12.6 to 90.95 ± 8.1 ($p < 0.001$), with a mean gain of 53.0 ± 13.9 points.
- The IMA decreased from $14.9 \pm 2.1^\circ$ to $10.0 \pm 3.0^\circ$ ($p < 0.001$), with a mean difference of $4.9 \pm 2.9^\circ$.
- The HVA decreased from $31.3 \pm 6.1^\circ$ to $11.8 \pm 5.7^\circ$ ($p < 0.001$), with a mean reduction of $19.4 \pm 5.8^\circ$.
- The FSS, expressed as lateral displacement, decreased from 0.89 ± 0.18 ($\approx 89\%$, Grade III) to 0.53 ± 0.30 ($\approx 53\%$, mean Grade II), with a mean reduction of 0.36 ± 0.29 ($36 \pm 29\%$, $p < 0.001$).

In the RImod group:

- The AOFAS score increased from 40.47 ± 13.1 to 93.4 ± 6.5 ($p < 0.001$), with a mean gain of 52.9 ± 13.9 points.

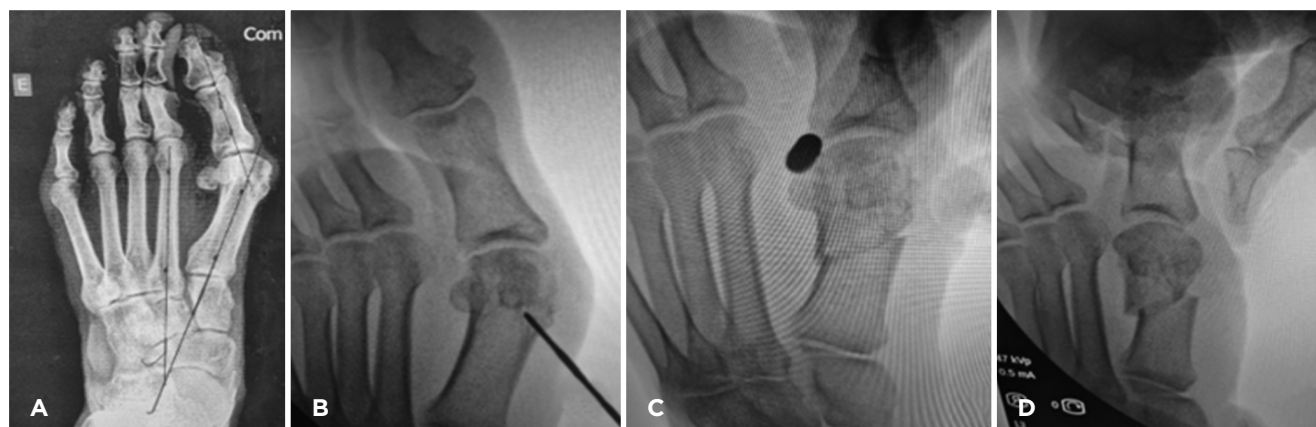


Figure 3. (A) Radiograph showing the moderate hallux valgus, (B) intraoperative radiograph demonstrating the point of onset of osteotomies, (C) radiograph after the RImod technique with lateral displacement of the metatarsal head and entry point of the tenotomy, (D) intraoperative radiograph showing the final result.

- The IMA decreased from $14.4 \pm 2.1^\circ$ to $10.0 \pm 2.8^\circ$ ($p < 0.001$), with a mean difference of $4.4 \pm 2.8^\circ$.
- The HVA decreased from $29.0 \pm 5.8^\circ$ to $11.0 \pm 4.4^\circ$ ($p < 0.001$), with a mean reduction of $18.0 \pm 6.3^\circ$.
- The FSS ranged from 0.82 ± 0.22 ($\approx 82\%$, Grade III/severe) to 0.51 ± 0.25 ($\approx 51\%$, Grade II/moderate), with a mean reduction of 0.31 ± 0.29 ($31\% \pm 29\%$, $p < 0.001$).

These findings demonstrate that both MIS techniques provided significant functional improvement and consistent radiographic correction, with a reduction in FSS from severe (Grade III) to moderate (Grade II) (Table 2).

Comparison between techniques (MICA group vs RImod group)

In the intergroup comparison (t-test of independent samples), no statistically significant differences were observed between the MICA group and the RImod group in any of the variables analyzed (Table 3):

- Functional gain (AOFAS difference)
 - MICA group: 53.0 ± 13.9
 - RImod group: 52.9 ± 13.9
 - $p = 0.98$
- IMA correction (pre-post difference)

Table 1. Sample characteristics and preoperative parameters of the MICA and RImod groups

Variables	MICA group (n = 38 feet)	RImod group (n = 43 feet)
Age (years), mean $\pm$ SD	54.0 ± 13.1	57.0 ± 12.8
Female (%)	89.5%	83.7%
Operated side (R/L)	52.6% R / 47.4% L	55.8% R / 44.2% L
Pre- AOFAS, mean $\pm$ SD	37.9 ± 13.0	40.5 ± 13.1
Pre- IMA ($^\circ$), mean $\pm$ SD	14.9 ± 2.1	14.4 ± 2.1
Pre- HVA ($^\circ$), mean $\pm$ SD	31.3 ± 6.1	29.1 ± 5.9
Pre lateral sesamoid (%), mean $\pm$ SD ¹	89 ± 18	82 ± 22

¹Pre lateral sesamoid: Fraction (0-1.00) of the lateral displacement of the fibular sesamoid in relation to the axis of the first metatarsal, converted into percentage (0%-100%). For interpretation according to Coughlin and Mann, it was considered: $< 50\%$ compatible with Grade I (mild); 50% - 75% with Grade II (moderate) and $> 75\%$ with Grade III (severe).

Table 2. Pre- and postoperative comparison of functional and radiographic variables in the MICA and RImod groups

Variables	Group	Preop (mean $\pm$ SD)	Postop (mean $\pm$ SD)	Difference (pre-post) (mean $\pm$ SD)	p intragroup	Unit
AOFAS	MICA	37.9 ± 12.6	90.95 ± 8.1	53.0 ± 13.9	< 0.001	points
AOFAS	RImod	40.47 ± 13.1	93.4 ± 6.5	52.9 ± 13.9	0.001	Points
IMA	MICA	14.9 ± 2.1	10.0 ± 3.0	4.9 ± 2.9	< 0.001	degree
IMA	RImod	14.4 ± 2.1	10.0 ± 2.8	4.4 ± 2.8	< 0.001	degree
HVA	MICA	31.3 ± 6.1	11.8 ± 5.7	19.4 ± 5.8	< 0.001	degree
HVA	RImod	29.0 ± 5.8	11.0 ± 4.4	18.0 ± 6.3	< 0.001	degree
Sesamoid (%)	MICA	80 ± 20	50 ± 30	36 ± 29	< 0.001	%
Sesamoid (%)	RImod	80 ± 20	50 ± 20	31 ± 29	< 0.001	%

AOFAS: American Orthopaedic Foot & Ankle Society; IMA: Intermetatarsal angle; HVA: Hallux valgus angle. Sesam: Fraction (0-1.00) of the lateral displacement of the fibular sesamoid in relation to the axis of the first metatarsal, converted into percentage (0%-100%). For interpretation according to Coughlin and Mann, it was considered: $< 50\%$ compatible with Grade I (mild); 50% - 75% with Grade II (moderate) and $> 75\%$ with Grade III (severe). Paired sample t-test; $p < 0.05$ considered significant.

Table 3. Pre- postoperative differences (Δ) between the MICA and RImod groups

Variables	Groups	Difference (pre-post) (mean $\pm$ SD)	p intragroup	Unit
AOFAS	MICA	53.0 ± 13.9	0.98	points
	RImod	52.9 ± 13.9		
IMA	MICA	4.9 ± 2.9	0.43	degree
	RImod	4.4 ± 2.8		
HVA	MICA	19.4 ± 5.8	0.30	degree
	RImod	18.0 ± 6.3		
Fibular sesamoid (displacement)	MICA	$36\% \pm 29\%$	0.41	%
	RImod	$31\% \pm 29\%$		

Δ = pre- postoperative value. Independent samples t-test; $p < 0.05$ considered significant.

- MICA group: $4.9 \pm 2.9^\circ$
- RImod group: $4.4 \pm 2.8^\circ$
- $p = 0.43$
- HVA Correction (pre-post difference)
 - MICA group: $19.4 \pm 5.8^\circ$
 - RImod group: $18.0 \pm 6.3^\circ$
 - $p = 0.30$
- FSS reduction (Δ Sesamoid)
 - MICA group: 0.36 ± 0.29 ($36 \pm 29\%$)
 - RImod group: 0.31 ± 0.29 ($31 \pm 29\%$)
 - $p = 0.41$

Thus, there was no evidence of statistical superiority of one technique over the other regarding functional gain (AOFAS), angular correction (IMA, HVA), or FSS in the postoperative period (Table 3). In both groups, the mean lateral FSS was reduced from severe (Grade III) to moderate (Grade II), with no statistically significant difference between the techniques regarding the magnitude.

Postoperative complications directly related to osteotomies were evaluated and categorized for both groups (Table 4). In the MICA group ($n = 38$), eight patients (21.1%) had at least one complication related to the surgical procedure. In the RImod group ($n = 43$), four patients (9.3%) had complications directly related to osteotomies. Statistical analysis showed no statistically significant difference in the overall complication rate between the two techniques ($p = 0.149$, Fisher's exact test).

In the MICA group, the most frequent complications were Complex Regional Pain Syndrome (CRPS) ($n = 2$; 5.3%), recurrence/hypocorrection ($n = 2$; 5.3%), and implant problems (screw) ($n = 2$; 5.3%). A fracture of the medial cortex of the proximal metatarsal fragment was observed in one patient (2.6%), requiring removal of one of the screws, and a soft-tissue complication (skin necrosis) in another (2.6%).

In the RImod group, complications were less frequent. One case of CRPS (2.3%), one of soft tissue complication (prolonged residual edema, 2.3%), one of nerve injury (superficial fibular neuropraxia, 2.3%), and one of malunion/

malposition (slight plantar flexion of the head of the M1, 2.3%) were recorded. None of the specific complications showed a statistically significant difference between the groups ($p > 0.05$ for all individual comparisons).

Discussion

This study compared the RImod and MICA techniques for moderate HV. Both techniques demonstrated significant improvements in AOFAS, HVA, IMA, and FSS, with no statistical differences between groups.

In the present study, the AOFAS score showed a mean improvement of 53.0 ± 13.9 points in the MICA group and 52.9 ± 13.9 points in the RImod group, with no statistically significant difference between the groups.

Carvalho et al.⁽¹⁴⁾ and Xavier et al.⁽¹⁵⁾, in retrospective studies using the MICA technique in moderate and severe HV, reported a mean preoperative AOFAS score of 43.97/45, with improvement of 90 points, similar to that found in the present study.

We observed in the literature a few studies that evaluated the RImod technique for HV correction. However, numerous studies were found that applied the classical Reverdin-Isham technique to correct HV, such as Bauer et al.⁽¹²⁾, who observed a significant increase in postoperative AOFAS score, with 89% patient satisfaction. The systematic review and meta-analysis by Sanchís-Soria et al.⁽¹⁶⁾, which analyzed 554 patients and 643 feet submitted to Reverdin-Isham osteotomy, also identified a mean improvement of 36.89 points in the AOFAS, corroborating the effectiveness of the technique. In this study, the RImod technique presented a gain greater than 50 points, surpassing the studies that presented the original technique^(12,16,17), possibly due to the greater stability of the modified osteotomy⁽⁷⁾.

The HVA correction was expressive in both groups: in the MICA group, the mean reduction was 19.5° while in the RImod group the reduction was 18.0° , results similar to the Vernois and Redfern study in the description of the MICA technique⁽⁴⁾.

The IMA correction showed a mean reduction of 4.9° (MICA) and 4.4° (RImod), indicating a good realignment of the first radius.

Table 4. Distribution of postoperative complications by surgical technique

Complication	MICA (n = 38)	RImod (n = 43)	p
CRPS	2 (5.3%)	1 (2.3%)	0.617
Recurrence/hypocorrection	2 (5.3%)	0 (0.0%)	0.239
Implant problems	2 (5.3%)	0 (0.0%)	0.239
Osteotomy-related fracture	1 (2.6%)	0 (0.0%)	0.469
Soft tissue complication/wound healing	1 (2.6%)	1 (2.3%)	1.000
Nerve injury	0 (0.0%)	1 (2.3%)	0.469
Malunion/malposition	0 (0.0%)	1 (2.3%)	0.469
Total of patients with complication	8 (21.1%)	4 (9.3%)	0.149

CRPS: Complex Regional Pain Syndrome. Values expressed as n (%). Fisher's exact test used for all comparisons. $p < 0.05$ considered statistically significant.

In another study⁽⁷⁾ conducted by our group, where the RImod technique was presented and used in 46 feet, the IMA decreased 4.3°, very close to the results in the present study, which was 4.4°.

Both techniques evaluated in the present study are complete distal osteotomies in which the M1 head is shifted laterally. This displacement alone allows correction of the distal metatarsal articular angle, which is why this parameter was not assessed in the present study^(7,15).

Assessment of fibular sesamoid position is an important radiographic parameter for evaluating the quality of HV surgical correction, as FSS reflects the degree of imbalance of the sesamoid apparatus and is a prognostic factor for deformity recurrence⁽¹⁾. In the present study, both groups demonstrated significant improvement in the fibular sesamoid position in the postoperative period, with no difference between the groups. De Prado et al.⁽¹⁰⁾ reported partial realignment of sesamoids in 62% of cases after the classical Reverdin-Isham percutaneous technique. The realignment of the sesamoid position observed in both techniques in the present study corroborates these findings, suggesting that both the lateral translation of the metatarsal head (MICA) and the reorientation of the joint surface (RImod) contribute to improving the relationship between the sesamoid and the metatarsal groove. Carvalho et al.⁽¹⁴⁾ and Xavier et al.⁽¹⁵⁾ also demonstrated significant improvement in the sesamoid position, corroborating that partial recentralization is a robust marker of good correction and lower recurrence in the medium term.

Postoperative complications directly related to osteotomies were observed in eight patients (21.1%) in the MICA group and in four patients (9.3%) in the RImod group. The profile of complications varied between techniques, which has clinical relevance.

In the MICA group, problems with implants (screw pain, migration, cortical fracture) accounted for 3 of the 8 cases. Carvalho et al.⁽¹⁴⁾ and Xavier et al.⁽¹⁵⁾ also reported a high incidence of pain related to screws (14.28%), often requiring removal.

In the RImod group, the absence of internal fixation eliminates the risk of implant-related complications, an inherent advantage of the technique in terms of its complication profile. However, the stability of osteotomy depends on the integrity of the medial bony step and postoperative compressive dressing, which may represent a limitation in patients with low adherence to treatment.

The infection rate was null in both groups, a result consistent with the literature that reports infection rates for percutaneous foot surgeries ranging from 0% to 3.5%^(3,12,17).

The findings of the present study suggest that both techniques are effective for treating moderate HV, and align with the growing evidence base, reinforcing the role of percutaneous techniques in HV therapy.

Limitations

This study has limitations inherent to its retrospective design, including the absence of randomization and blinding of evaluators, which can introduce selection and measurement biases. The sample size, although adequate for a comparative analysis, may be insufficient to detect small differences between groups. In addition, the absence of formal assessment of intraobserver reliability constitutes an additional methodological limitation. Finally, the mean follow-up may be insufficient to detect late complications, such as recurrence of the deformity and transfer metatarsalgia.

Conclusion

This study compared the effectiveness of RImod and MICA techniques in the treatment of moderate HV. Both techniques demonstrated significant clinical and radiographic improvements, with functional gains in AOFAS score and substantial angular corrections in HVA, IMA, and fibular sesamoid position. There was no statistically significant difference between the groups regarding the magnitude of these improvements, validating both techniques.

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Original Article

Plate-mediated versus lag screw-driven compression in first metatarsophalangeal joint arthrodesis for end-stage hallux rigidus: A retrospective comparative cohort study

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Abstract

Objective: To compare two technical sequences using the same fixation construct but differing in the mechanism responsible for primary compression across the arthrodesis site.

Methods: A retrospective cohort study was performed including consecutive patients who underwent first metatarsophalangeal joint (MTPJ) arthrodesis for advanced hallux rigidus (Coughlin and Shurnas grades 3 and 4) between January 2015 and December 2024. All procedures were performed using cup-and-cone joint preparation, a low-profile dorsal plate, and an oblique cannulated screw. In technique 1 (T1), compression was generated primarily through the dynamic compression mechanism of the dorsal plate, whereas in technique 2 (T2), compression was generated primarily by the oblique lag screw. Clinical outcomes were assessed using the American Orthopaedic Foot & Ankle Society (AOFAS) hallux metatarsophalangeal-interphalangeal scale and the visual analog scale (VAS) for pain. Radiographic union, time to union, and complications were recorded.

Results: Fifty-five patients (68 feet) were included, comprising 39 feet treated with T1 and 29 feet treated with T2. Both techniques resulted in significant improvements in AOFAS and VAS scores ($p < 0.001$ for all comparisons). Nonunion occurred in 3 of 39 feet (7.7%) in T1 and 1 of 29 feet (3.4%) in T2 ($p = 0.631$). No statistically significant differences were observed between groups regarding final AOFAS scores, final VAS scores, or overall complication rates. Mean time to union was significantly shorter in T2 than in T1 (6.89 ± 0.79 vs 7.94 ± 1.17 weeks; $p < 0.001$). After adjustment for age and baseline clinical differences, T2 remained independently associated with faster union (adjusted coefficient -0.80 weeks; 95% confidence interval, -1.46 to -0.15; $p = 0.015$).

Conclusions: First MTPJ arthrodesis using a dorsal plate combined with an oblique cannulated screw provided reliable union, substantial pain relief, and significant functional improvement regardless of the sequence of implant application. Although both compression strategies yielded comparable union rates and clinical outcomes, lag screw-driven compression was associated with a significantly shorter time to fusion. These findings suggest that direct interfragmentary compression generated by the oblique lag screw may modestly accelerate arthrodesis consolidation without increasing complications.

Level of Evidence III; Retrospective Comparative Cohort Study.

Keywords: Hallux rigidus; Arthrodesis; Metatarsal bone; Bone screws.

Study performed at Hospital Israelita Albert Einstein, São Paulo, SP, Brazil.

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Introduction

Hallux rigidus (HR) is the second most common pathology affecting the human great toe and is characterized by progressive restriction of motion at the first metatarsophalangeal joint (MTPJ). This degenerative condition is associated with pain, swelling, and progressive articular cartilage degeneration, resulting in functional limitation and impaired gait mechanics⁽¹⁾.

This condition has several proposed etiologies, although its exact cause remains unclear. The most frequently cited causes of degenerative disease of the first MTPJ include osteochondral injury after repetitive microtrauma due to local biomechanical alterations, post-traumatic osteoarthritis after a single trauma or chronic MTPJ instability, turf-toe injury, local inflammation related to systemic diseases, primary osteoarthritis, iatrogenic causes, and osteochondritis dissecans⁽¹⁻⁶⁾.

The main constitutional factors associated with HR include first metatarsal adductus, a chevron-shaped or squared distal articular surface of the first metatarsal, abnormalities in first metatarsal length (either short or long), flatfoot, metatarsus primus elevatus, hallux valgus interphalangeal, and female sex⁽¹⁾.

Patients typically present with an insidious onset of forefoot pain involving the great toe that worsens during walking and improves with rest, usually associated with stiffness of the first MTPJ^(4,7-9).

Physical examination demonstrates decreased passive range of motion of the first MTPJ, whose normal range of motion is approximately 80°. Initially, flexion is maintained but decreases as arthritis progresses. A dorsal bony prominence—dorsal bunion—may also be visible or palpable (Figure 1)^(1,11-13).

Radiographs typically show irregular narrowing of the joint space, flattening and widening of the first metatarsal head, subchondral cysts and sclerosis, enlargement of the base of the proximal phalanx, hypertrophy of the sesamoids, and progressive gleno-sesamoid osteoarthritis. The typical aspect of dorsal osteophytes is the appearance of melted wax (Figure 2)^(1,13).

In patients presenting with restricted first MTPJ motion, no radiographic evidence of degenerative changes, and associated synovitis, the differential diagnosis should include functional hallux rigidus⁽¹⁴⁾ and inflammatory arthropathies⁽¹⁵⁾.

The Coughlin and Shurnas^(1,14,15) classification remains the most widely adopted system for grading HR, incorporating the degree of first MTPJ dorsiflexion, radiographic features, and clinical manifestations, particularly pain. In grade 0, first MTPJ dorsiflexion ranges from 40° to 60°, with no associated pain or radiographic abnormalities. In grade 1, dorsiflexion ranges from 30° to 40° and is accompanied by early radiographic changes, including small dorsal osteophytes and mild joint-space narrowing, as well as mild pain. In grade 2, first MTPJ dorsiflexion ranges from 10° to 30°, with the



Figure 1. Classic clinical aspect of hallux rigidus. (A) Dorsal bunion (B) Significant limitation of metatarsophalangeal joint extension (C) Significant limitation of metatarsophalangeal joint flexion.



Figure 2. Main radiographic findings of the hallux rigidus. (A) Reduction of the metatarsophalangeal joint space (B) Exuberant dorsal osteophyte in the shape of “melted wax”.

presence of periarticular osteophytes and moderate pain. In grades 3 and 4, dorsiflexion is less than 10°, and radiographs typically demonstrate extensive osteophyte formation and subchondral cysts. Clinically, grade 3 is characterized by significant pain at the extremes of motion, whereas grade 4 is distinguished by pain throughout the mid-range of motion, including passive joint movement⁽⁶⁾.

First MTPJ arthrodesis is widely regarded as the gold-standard treatment for advanced degenerative disease of the first MTPJ, irrespective of the underlying etiology, including end-stage HR (Coughlin and Shurnas grades 3 and 4), inflammatory arthropathies, and post-traumatic arthritis. The procedure reliably restores or maintains first-ray length and stability, improves gait biomechanics, and provides durable pain relief, resulting in high rates of patient satisfaction^(4,14).

A historical review of first MTPJ arthrodesis demonstrates a consistent improvement in clinical and radiographic outcomes over time. This progress can be largely attributed to advances in soft-tissue preservation techniques, optimization of joint surface preparation, greater attention to achieving physiological and functional alignment, and the development of more reliable fixation constructs^(5,15). Currently, there is little controversy regarding the use of convex-concave (cup-and-cone) reamers for joint preparation and the application of plate-and-screw constructs, in various configurations, for first MTPJ arthrodesis fixation⁽¹⁶⁾.

The primary objective of the present study was to compare the outcomes of first MTPJ arthrodesis performed for end-stage HR using the same implants for two surgical technical sequences: plate-mediated vs lag screw-driven compression.

They differed in the component responsible for generating the primary compression across the fusion site, namely the dorsal plate (Technique 1 – T1)^(12,15,16) or the oblique compression lag-screw (Technique 2 – T2)^(16,17). Their potential influence on union rates, clinical outcomes, and complications was evaluated.

Methods

Study design

This retrospective cohort study was conducted at a single tertiary referral foot and ankle center between January 2015 and December 2024 and was designed and reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement.

Ethical approval

The study protocol was approved by the Institutional Review Board under the number 82911818.0.0000.0071. The study was conducted in accordance with the ethical standards of the Declaration of Helsinki.

All patients provided written informed consent authorizing their participation in the study and the use of their anonymized clinical and imaging data for scientific publication.

Inclusion criteria

- Adults ≥ 18 years with advanced primary or secondary osteoarthritis of the first MTPJ, classified as Coughlin and Shurnas grade 3 or 4.

2. Consecutive patients who underwent first MTPJ arthrodesis using a dorsal plate and an obliquely oriented screw.

Exclusion criteria

1. Associated acute fractures involving the foot or ankle.
2. Congenital or acquired forefoot deformities associated with severe shortening of the first ray.
3. Benign or malignant tumors of the foot or ankle.

Outcome measures

Demographic and clinical data, including sex, age, laterality, and comorbidities, were collected. Functional outcomes were assessed using the American Orthopaedic Foot & Ankle Society (AOFAS) hallux metatarsophalangeal-interphalangeal scale and the visual analog scale (VAS) for pain preoperatively and at final follow-up. Radiographic union, time to union, and postoperative complications were also evaluated.

Patients were subsequently divided into two groups according to the sequence of implant application. Although both groups received the same fixation construct, they differed in relation to the component responsible for generating the primary compression across the arthrodesis site (the dorsal plate or the oblique compression lag-screw). Union rates, clinical outcomes, and complication rates were then compared between the two fixation strategies.

Surgical technique

All procedures were performed through a dorsal longitudinal approach to the first MTPJ (Figure 3A). After careful dissection of the extensor hood and protection of the extensor hallucis longus and brevis tendons, the joint was exposed, and the degree of degeneration and osteophyte removal were assessed (Figure 3B and 3C).

Following adequate exposure, the longitudinal axis of the first metatarsal was identified using a Kirschner wire (K-wire) as a guide. A concave reamer of appropriate diameter was then used to remove the remaining articular cartilage from the metatarsal head and expose the underlying subchondral bone (Figure 3D). The corresponding articular surface of the proximal phalanx was subsequently prepared using a matching convex reamer (Figure 3E). This technique generated complementary concave-convex surfaces that provided a broad contact area, intrinsic stability, and optimal congruency between the fusion surfaces.

To enhance osseous healing, multiple perforations were created in both subchondral surfaces using a 1.2-mm K-wire (Figure 3F). The arthrodesis was positioned in approximately 10° to 15° of dorsiflexion and 10° of valgus relative to the first metatarsal axis. Precontoured low-profile dorsal plates incorporating these corrections were used as alignment guides and fixation devices. Temporary fixation was obtained with a K-wire inserted obliquely from the medial aspect of the proximal phalanx toward the metatarsal head (Figure 3G, H, and I).

Technique 1: Plate-generated compression

In T1, the dorsal plate was initially secured to the proximal phalanx using bicortical screw fixation. Compression across the arthrodesis site was subsequently achieved through the dynamic compression mechanism provided by the proximal oblong holes of the plate. Final fixation was completed with insertion of a cannulated screw over the previously placed oblique K-wire. In this construct, compression was generated primarily by the dorsal plate, whereas the oblique screw functioned as a neutralization device.

Technique 2: Screw-generated compression

In T2, the dorsal plate was initially fixed to the proximal phalanx in the same manner described for T1. An oblique cannulated lag-screw was then inserted over the guide K-wire, generating interfragmentary compression across the fusion site. The remaining proximal plate screws were subsequently inserted using standard bicortical fixation without activation of the dynamic compression mechanism of the plate. In this construct, compression was generated primarily by the oblique lag-screw, whereas the dorsal plate functioned as a neutralization device.

Postoperative protocol

Postoperatively, patients remained non-weight-bearing until radiographic evidence of union was observed. Fusion was subsequently confirmed by computed tomography (CT). Time to union was defined as the interval between surgery and CT confirmation of fusion involving more than 50% of the intended arthrodesis surface.

Following confirmation of union, a structured physiotherapy program was initiated, with gradual progression of weight-bearing until unrestricted ambulation with full forefoot loading was achieved.

Statistical methods

Given the retrospective design of this study, no formal “a priori” sample size calculation was performed. Instead, all consecutive patients who met the eligibility criteria during the study period were included to maximize statistical power and minimize selection bias. The final sample size was therefore determined by the number of eligible cases available in the institutional database. Effect estimates were reported with 95% confidence intervals whenever appropriate, and the possibility of type II error due to limited sample size was considered in the interpretation of non-significant findings.

The unit of analysis was the operated foot. A secondary sensitivity analysis was also performed at the patient level because some patients contributed bilateral procedures.

Continuous variables were summarized as mean $\pm$ standard deviation and also inspected for normality using the Shapiro-Wilk test. Given the sample size and non-normal distributions in several variables, non-parametric Mann-Whitney U tests were considered alongside Welch t-tests.



Figure 3. Surgical Technique. (A) Dorsal skin incision (B) Macroscopic aspect of the head of the first metatarsal showing an extensive area of subchondral bone exposure (C) Partial view of the proximal articular facet of the proximal phalanx of the hallux and the exuberant dorsal osteophyte of the metatarsal head (D) Debridement of the metatarsal head with a concave tool (E) Debridement of the articular facet of the phalanx with a convex tool (F) Multiple perforations of the subchondral bone of both complementary bone surfaces (G) Dorsal view of the metatarsophalangeal joint immediately after placement of both fixation elements of the arthrodesis area (oblique screw and dorsal plate) (H-I) Intraoperative radiographs (AP and lateral) demonstrating the positioning of the material used for bone fixation.

For categorical outcomes, Fisher exact tests were used. Paired preoperative vs postoperative comparisons were assessed with paired t-tests and Wilcoxon signed-rank tests.

The primary outcome was nonunion/pseudarthrosis. Secondary outcomes included time to union, AOFAS score, VAS pain score, AOFAS improvement, VAS improvement, and complications.

The threshold for statistical significance was two-sided $\alpha = 0.05$, with 95% confidence intervals. Exploratory adjusted models were performed using heteroscedasticity-robust linear regression.

Because only four nonunion events were present, multi-variable logistic regression for nonunion was considered statistically unstable and was not used as a confirmatory model.

Results

Demographic characteristics

A total of 55 patients (68 feet) were included in the study. Thirty-three patients (39 feet) underwent arthrodesis using T1, whereas 22 patients (29 feet) were treated using T2. Bilateral procedures were performed in six patients in the T1 group and in seven patients in the T2 group.

The study population was predominantly female, comprising 25 women (75.8%) and eight men (24.2%) in T1, and 16 women (72.7%) and six men (27.3%) in T2. The mean age at the time of surgery was 59 years (range, 42-77 years) in T1 and 65 years (range, 38-77 years) in T2.

Regarding laterality, 24 procedures (61.5%) involved the right foot and 15 (38.5%) the left foot in T1, whereas 15 procedures (51.7%) involved the right foot and 14 (48.3%) the left foot in T2.

Patients included in T1 presented lower preoperative functional scores, with a mean AOFAS score of 33 points compared with 40 points in T2. Similarly, preoperative pain levels were slightly higher in T1 (VAS 7 vs 6). Rheumatoid arthritis was more prevalent in T1 (11 patients) than in T2 (2 patients) (Table 1).

The statistical data which involved 39 feet in group T1 and 29 feet in group T2, shows that the groups were not fully comparable at baseline: patients in T2 were older (65.24 ± 11.59 vs 58.95 ± 8.91 years; $p = 0.018^*$), had higher preoperative AOFAS scores (39.83 ± 12.36 vs 31.87 ± 12.97 ; $p = 0.013^*$), and lower preoperative VAS scores (5.97 ± 0.82 vs 7.41 ± 0.72 ; $p < 0.001^*$). Sex distribution and operated side did not show statistically significant differences between groups (Table 2).

Both techniques produced significant clinical improvement. In T1, AOFAS score improved from 31.87 ± 12.97 to 80.33 ± 6.21 points (Wilcoxon $p < 0.001$), and VAS improved from 7.41 ± 0.72 to 1.49 ± 1.21 (Wilcoxon $p < 0.001$). In Technique

Table 1. Demographic Characteristics

	T1	%	T2	%
Patients (n)	33	60.0%	22	40.0%
Feet (n)	39	57.4%	29	42.6%
Bilateral surgery	6	18.2%	7	31.8%
Mean age (min-max)	59 (42-77)	---	65 (38-77)	---
Sex - Female	25	75.8%	16	72.7%
Sex - Male	8	24.2%	6	27.3%
Side - Right	24	61.5%	15	51.7%
Side - Left	15	38.5%	14	48.3%
RA patients	11	33.3%	1	4.5%
Preoperative AOFAS	33	---	40	---
Preoperative VAS	7	---	6	---

T1: Technique 1; T2: Technique 2; RA: Rheumatoid arthritis; AOFAS: American Orthopaedics Foot & Ankle Society; VAS: Visual analog scale.

Table 2. Baseline and postoperative continuous variables

Variable	T1 mean $\pm$ SD	T2 mean $\pm$ SD	Mean difference T2-T1	95% CI	Welch p	Mann-Whitney p
Age (years)	58.95 ± 8.91	65.24 ± 11.59	6.29	1.11 to 11.48	0.018*	0.007*
AOFAS preoperative	31.87 ± 12.97	39.83 ± 12.36	7.96	1.77 to 14.14	0.013*	0.015*
VAS preoperative	7.41 ± 0.72	5.97 ± 0.82	-1.44	-1.83 to -1.06	<0.001*	<0.001*
AOFAS postoperative	80.33 ± 6.21	83.90 ± 7.77	3.56	0.05 to 7.08	0.047*	0.006*
VAS postoperative	1.49 ± 1.21	1.17 ± 1.28	-0.31	-0.93 to 0.30	0.310	0.245
AOFAS improvement	48.46 ± 13.18	44.07 ± 11.74	-4.39	-10.45 to 1.67	0.153	0.203
VAS improvement	5.92 ± 1.53	4.79 ± 1.47	-1.13	-1.86 to -0.40	0.003*	0.004*
Time to union, weeks#	7.94 ± 1.17	6.89 ± 0.79	-1.05	-1.54 to -0.56	<0.001*	<0.001*

SD: Standard deviation; CI: Confidence interval; T1: Technique 1; T2: Technique 2; AOFAS: American Orthopaedics Foot & Ankle Society; VAS: Visual analog scale.

*All statistically significant values are marked with an asterisk. # Time to union excludes feet classified as pseudarthrosis. Positive differences indicate higher values in T2; negative differences indicate lower values in T2.

2, AOFAS improved from 39.83 ± 12.36 to 83.90 ± 7.77 points (Wilcoxon $p < 0.001$), and VAS improved from 5.97 ± 0.82 to 1.17 ± 1.28 (Wilcoxon $p < 0.001$) (Table 3).

The primary outcome, nonunion/pseudarthrosis, occurred in 3 of 39 feet (7.7%) treated with T1 and in 1 of 29 feet (3.4%) treated with T2. This difference was not statistically significant (Fisher exact test $p = 0.631$) (Table 4).

At the patient level, nonunion occurred in 3 of 33 patients in T1 and in 1 of 22 patients in T2 (Fisher exact test $p = 0.642$) (Table 5).

Time to union among consolidated cases was significantly shorter in T2 than in T1 (6.89 ± 0.79 vs 7.94 ± 1.17 weeks; Welch $p < 0.001$; Mann-Whitney $p < 0.001$) (Figure 4). After adjustment for age, preoperative AOFAS and preoperative VAS, T2 remained associated with a shorter time to union (adjusted coefficient, -0.80 weeks; 95% CI, -1.46 to -0.15; $p = 0.015$).

Unadjusted postoperative AOFAS was slightly higher in T2 (83.90 ± 7.77 vs 80.33 ± 6.21 ; Welch $p = 0.047$), but this difference was not maintained after adjustment for baseline AOFAS and age ($p = 0.299$). AOFAS improvement was similar between groups (44.07 ± 11.74 vs 48.46 ± 13.18 ; Welch $p = 0.153$). VAS improvement was greater in T1 in the unadjusted analysis (5.92 ± 1.53 vs 4.79 ± 1.47 ; $p = 0.003$), but this finding should be interpreted in the context of

significantly higher baseline pain in T1; after adjustment for baseline VAS and age, the technique effect was no longer significant ($p = 0.302$) (Table 6).

The available data therefore do not demonstrate a statistically significant superiority of one technique over the other regarding nonunion, final pain, final function, or global complications. However, T2 showed a consistent association with shorter time to union, even after adjustment for baseline

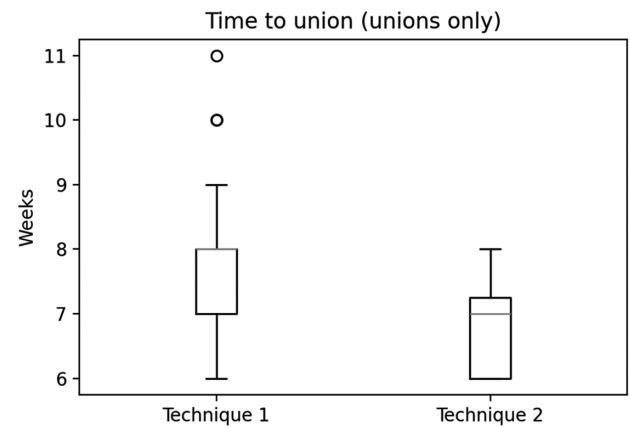


Figure 4. Time to union among consolidated cases.

Table 3. Within-group pre- to postoperative changes

Technique	Outcome	n	Preoperative mean $\pm$ SD	Postoperative mean $\pm$ SD	Mean improvement	95% CI	Wilcoxon p
T1	AOFAS	39	31.87 $\pm$ 12.97	80.33 $\pm$ 6.21	48.46	44.19 to 52.73	<0.001*
T1	VAS	39	7.41 $\pm$ 0.72	1.49 $\pm$ 1.21	5.92	5.43 to 6.42	<0.001*
T2	AOFAS	29	39.83 $\pm$ 12.36	83.90 $\pm$ 7.77	44.07	39.60 to 48.53	<0.001*
T2	VAS	29	5.97 $\pm$ 0.82	1.17 $\pm$ 1.28	4.79	4.23 to 5.35	<0.001*

SD: Standard deviation; CI: Confidence interval; T1: Technique 1; T2: Technique 2; AOFAS: American Orthopaedics Foot & Ankle Society; VAS: Visual analog scale. * All statistically significant values are marked with an asterisk.

Table 4. Primary outcome and categorical complications

Outcome	T1	T2	Risk difference T2-T1	Fisher p	Odds ratio	Risk ratio T2/T1	RR 95% CI
Pseudarthrosis	3/39 (7.7%)	1/29 (3.4%)	-4.2 pp	0.631	2.33	0.45	0.05 to 4.09
Wound complication	1/39 (2.6%)	0/29 (0.0%)	-2.6 pp	1.000	Inf	0.00	NA
Any recorded complication	3/39 (7.7%)	1/29 (3.4%)	-4.2 pp	0.631	2.33	0.45	0.05 to 4.09

CI: Confidence interval; T1: Technique 1; T2: Technique 2. pp = percentage points. Risk ratios are unstable because of the very low number of events. * All statistically significant values are marked with an asterisk.

Table 5. Patient-level sensitivity analysis

Outcome	T1	T2	Fisher p	Interpretation
Pseudarthrosis	3/33 (9.1%)	1/22 (4.5%)	0.642	No statistically significant patient-level difference.
Any recorded complication	3/33 (9.1%)	1/22 (4.5%)	0.642	No statistically significant patient-level difference.

T1: Technique 1; T2: Technique 2. * All statistically significant values are marked with an asterisk.

differences. This finding is compatible with the biomechanical rationale of direct interfragmentary compression using the oblique lag screw, with the dorsal plate acting as a neutralization device.

Discussion

The principal finding of the present study was that first MTPJ arthrodesis performed with a dorsal plate and an obliquely oriented cannulated screw produced predictable and satisfactory outcomes regardless of the sequence of implant application. Both fixation strategies resulted in substantial improvement in pain and function, high union rates, and low complication rates. No statistically significant differences were observed regarding pseudarthrosis, final AOFAS scores, final VAS scores, or overall complications (Figure 5). However, arthrodesis in which compression was generated primarily by the oblique lag screw achieved union significantly earlier than

those in which compression was generated primarily through the plate compression mechanism. This difference remained significant after adjustment for age and baseline clinical differences.

First MTPJ arthrodesis is widely accepted as the gold-standard treatment for advanced HR and other end-stage degenerative conditions of the joint^(12,15). Numerous studies have demonstrated union rates exceeding 90%, together with substantial improvements in pain, function, and patient satisfaction⁽¹⁷⁻²⁴⁾. The results observed in the present series are consistent with those reported by Coughlin et al. and by contemporary investigations evaluating dorsal plate and interfragmentary screw constructs^(12,15,17-24). The union rates observed in both groups, as well as the magnitude of improvement in AOFAS and VAS scores, confirm the reliability of modern plate-and-screw fixation systems for first MTPJ arthrodesis.

Table 6. Exploratory adjusted models

Outcome	Adjustment model	Adjusted effect of T2	95% CI	p value	n
Postoperative AOFAS	Age + preoperative AOFAS	2.18	-1.94 to 6.30	0.299	68
Postoperative VAS	Age + preoperative VAS	-0.54	-1.56 to 0.48	0.302	68
AOFAS improvement	Age + preoperative AOFAS	2.18	-1.94 to 6.30	0.299	68
VAS improvement	Age + preoperative VAS	0.54	-0.48 to 1.56	0.302	68
Time to union, (weeks)	Age + preoperative AOFAS + preoperative VAS	-0.80	-1.46 to -0.15	0.015*	64

CI: Confidence interval; T1: Technique 1; T2: Technique 2; AOFAS: American Orthopaedics Foot & Ankle Society; VAS: Visual analog scale. The coefficient represents T2 minus T1. Negative values for time to union indicate faster union with Technique 2. These models are exploratory and should not be overinterpreted as causal estimates. * All statistically significant values are marked with an asterisk.



Figure 5. Weigh-bearing radiographs at three years postoperative (right side) and two years postoperative (left side) of a patient who underwent metatarsophalangeal joint arthrodesis (T1). (A) Dorsoplantar view (B) Lateral view. The solid consolidation achieved was noticeable, and the patient remained without complaints at the time of the evaluation.

Although the overall outcomes were similar, the shorter time to union observed in T2 deserves particular attention. The biomechanical explanation is plausible^(16,17,19). In T2, interfragmentary compression is generated directly by the oblique lag screw before definitive plate fixation. This sequence may optimize compression at the arthrodesis interface and reduce micromotion during the early stages of healing. The dorsal plate subsequently acts primarily as a neutralization device, protecting the construct from bending and rotational forces. In contrast, T1 relies initially on the dynamic compression mechanism of the plate, while the oblique screw functions mainly as a supplemental stabilizer. While the present study was not designed as a biomechanical investigation, the findings suggest that the source and sequence of compression generation may influence the biological tempo of fusion.

An additional observation concerns the distribution of rheumatoid arthritis between groups. Patients with rheumatoid arthritis represented approximately one-third of the cohort treated with T1 but were uncommon in T2. Historically, inflammatory arthropathies have been associated with impaired bone quality, increased deformity severity, and a potentially greater risk of nonunion. Despite this imbalance, union rates and final clinical outcomes remained favorable in both groups. Although the sample size precludes definitive conclusions, these findings support previous reports indicating that modern fixation constructs can achieve reliable arthrodesis—even in patients with inflammatory joint disease—and serve as an important resource for salvage of pseudarthrosis cases (Figure 6).

The present study has several limitations. Its retrospective design inherently introduces the possibility of information

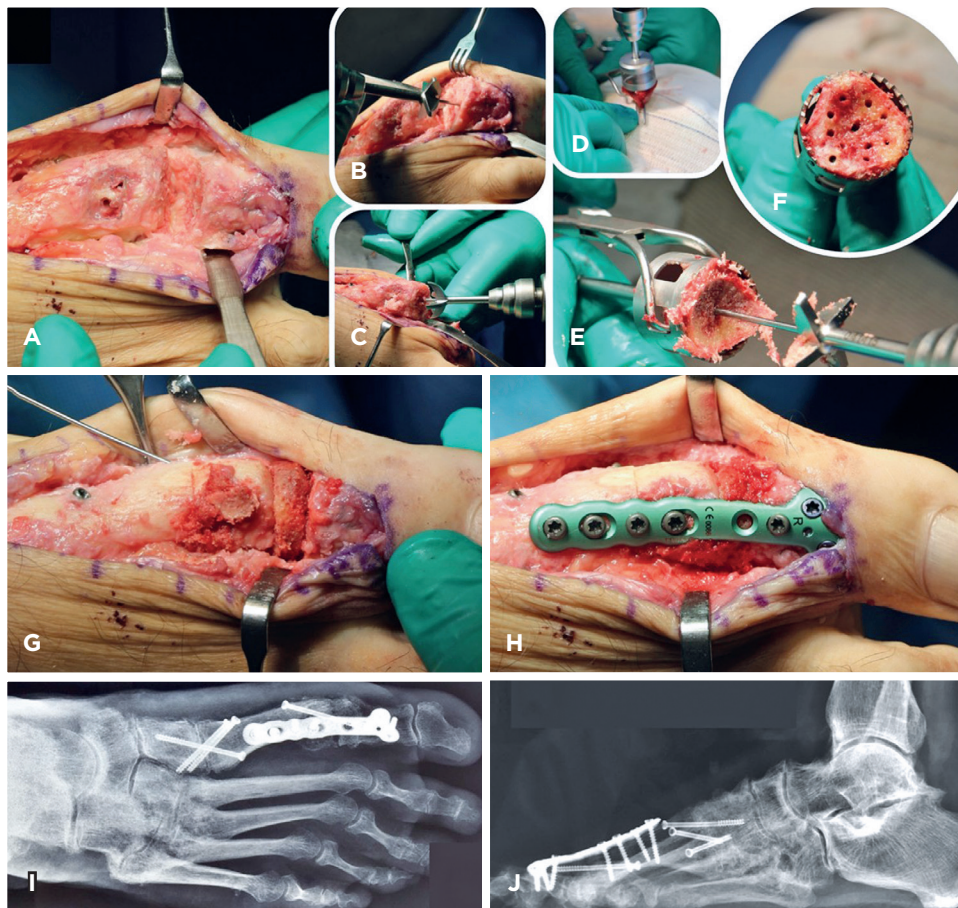


Figure 6. A. Dorsal view of the first metatarsophalangeal joint of a patient with pseudarthrosis. (B) Preparation of the hallux phalanx (C) Preparation of the first metatarsal head (D) Due to bone loss, an autologous graft was harvested from the iliac spine (E) Both surfaces of the iliac graft were prepared using the same reamers employed on the phalanx and metatarsal, creating one concave and one convex surface (F) Multiple perforations made in the autologous bone graft (G-H) After placing the bone graft into the bone defect, the construct was fixed with an oblique K-wire, followed by a dorsal plate and an oblique screw. In this case, the dorsal plate provided compression, while the oblique screw acted as a neutralization element (I-J). Radiographs at 6 months post-operatively, showing solid union at the arthrodesis site.

bias and residual confounding. The absence of randomization resulted in baseline differences between groups, including age, preoperative AOFAS scores, preoperative pain levels, and the prevalence of rheumatoid arthritis. Although exploratory adjusted analyses were performed, unmeasured confounding variables may still have influenced the results. In addition, the study was conducted at a single specialized foot and ankle center, which may limit external validity. Finally, because only four cases of pseudarthrosis were observed, the study may have lacked sufficient statistical power to detect small differences in rare complications, and the possibility of a type II error cannot be excluded.

Despite these limitations, the study has important strengths. All patients underwent surgery using the same fixation approach, identical joint preparation methods, and similar postoperative rehabilitation protocols. Furthermore, fusion was confirmed by CT, providing a more rigorous assessment of union than conventional radiography alone. To our knowledge, few clinical studies have specifically investigated whether the component responsible for generating primary compression within a plate-and-screw construct influences the outcomes of first MTPJ arthrodesis. The present findings suggest that both strategies provide excellent clinical results; however, the use of the oblique lag screw as the primary

compression device may facilitate earlier union without increasing complications. Future prospective and randomized studies are required to confirm these observations and determine their clinical relevance.

Conclusion

First metatarsophalangeal joint arthrodesis using a dorsal plate combined with an oblique cannulated screw provided reliable union, substantial pain relief, and significant functional improvement in patients with end-stage hallux rigidus.

Fusion in which primary compression was generated by the oblique lag screw demonstrated a significantly shorter time to union. Both plate-mediated compression and lag screw-driven compression resulted in satisfactory clinical and radiographic outcomes, with no statistically significant differences in nonunion, final pain scores, final functional scores, or overall complications.

These findings suggest that both fixation sequences are safe and effective, although lag screw-driven compression may offer a modest advantage in accelerating radiographic consolidation. Further prospective studies with larger samples are required to confirm whether this difference has clinically meaningful implications.

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Original Article

Five-year bibliometric analysis of the Journal of the Foot & Ankle (2020-2025)

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Abstract

Objective: To characterize productivity, document-type composition, authorship, geography, and citation impact of the Journal of the Foot & Ankle (JFA) over its first five years (2020-2025) following its 2020 refoundation.

Methods: All peer-reviewed articles published in JFA between January 2020 and December 2025 were retrieved from OpenAlex and cross-checked against Crossref. The 22 articles of the founding issue (V14 N1) were registered under the predecessor journal's ISSN and recovered separately. Meeting abstracts, articles outside the study period, editorials, and one tribute were excluded. Document type was classified by manual review of each issue's Table of Contents. Author productivity was measured by leadership appearances (first or last author), country and institution by whole counting at the article level, and citation impact by cumulative counts and the journal h-index. Analysis was performed in R.

Results: A total of 334 articles were included, with a mean of 56 per year. Original articles accounted for 68.9%. Unique authors totaled 1,037, with a mean of 5.2 per article. Brazil was the predominant country in 185 articles (55.4%), followed by the United States (10.2%) and Argentina (6.0%). The most productive institution was the Universidade Federal de São Paulo (23 articles). The total accumulated 272 citations with a journal h-index of 6. César de César Netto led the leadership ranking with 15 appearances (14 as senior author). International collaboration had a mean of 10.5%.

Conclusion: JFA has consolidated as the principal Ibero-American outlet for foot and ankle research, with a Brazilian-anchored yet regionally inclusive authorship, sustained Diamond Open Access, and an early but rising citation footprint.

Level of Evidence IV; Bibliometric, Descriptive Observational Study.

Keywords: Bibliometrics; Foot and ankle; Orthopedics; Latin America; Open access publishing.

Introduction

Bibliometric analysis quantifies the scholarly output of a journal, a research field or an academic community. Beyond simple production counts, bibliometric studies characterize authorship structure, collaboration patterns, geographic distribution, citation impact, and thematic specialization, providing an evidence base from which editors, authors, and readers can interpret a journal's trajectory⁽¹⁻³⁾.

In Latin American orthopedic publishing, regional journals play a distinctive role. They lower the language and cost barriers of major Anglophone outlets, foster collaboration across countries that share clinical realities, and provide a venue in which clinicians without prior international visibility can publish peer-reviewed work. At the same time, regional journals face systemic challenges in achieving indexing in commercial databases, accumulating citations, and competing for high-quality submissions⁽⁴⁻⁷⁾.

Study performed at the Duke University School of Medicine, Department of Orthopedic Surgery, Foot and Ankle Division, Durham, NC, USA 27710.

Correspondence: Julieta Brué, Duke University School of Medicine, Department of Orthopedic Surgery, Foot and Ankle Division, Durham, NC, USA **Email:** brue@duke.edu. **Conflicts of interest:** Cesar de Cesar Netto, MD, PhD, reports the following disclosures: nonfinancial roles as president of the International WBCT Society, editor-in-chief of Foot and Ankle Clinics, and committee member of AOFAS. **Source of funding:** None. **Date received:** July 01, 2026. **Date accepted:** July 28, 2026.

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The Journal of the Foot & Ankle (JFA, eISSN 2675-2980) was formally established in 2019 and launched its first issue in April 2020 through the unification of two predecessor regional journals: the Brazilian *Revista da ABTPé*, later renamed *Scientific Journal of the Foot & Ankle* (eISSN 2595-1459) in 2016 when the journal transitioned to English-language publication, and the Argentine *Tobillo y Pie*^(8,9). The refounded journal is published by the *Associação Brasileira de Medicina e Cirurgia do Tornozelo e Pé (ABTPé)* and serves the foot and ankle community of the *Federación Latinoamericana de Medicina y Cirugía de la Pierna y Pie (FLAMeCIPP)*. Volume numbering was preserved from predecessor journals, so the first issue of the unified JFA appeared as volume 14, number 1. Volume 19 (2025) marked the transition from quarterly to continuous publication and coincided with the 20th anniversary of the journal lineage.

Despite the visibility of the journal within the regional foot-and-ankle community, no published bibliometric analysis of its output, authorship or impact exists. The objective of this study is to characterize the publication output of JFA over its first five years (2020-2025), describing productivity, document-type composition, authorship structure (including a leadership-position analysis), geographic and institutional distribution, citation patterns and international collaboration.

Methods

Study design and analysis definition

This is a retrospective bibliometric analysis of peer-reviewed research articles published in the JFA between 1 January 2020 (Volume 14, Number 1) and 31 December 2025 (Volume 19, Number 3). The study used only publicly available bibliographic metadata. Institutional Review Board approval was not required.

Data sources and the founding-issue artifact

The JFA is currently indexed in Google Scholar⁽¹⁰⁾ and the Directory of Open Access Journals (DOAJ)⁽¹¹⁾, but not yet in Scopus, Web of Science, or PubMed/MEDLINE⁽¹²⁻¹⁴⁾. OpenAlex⁽¹⁵⁾ was therefore adopted as the primary data source, given its comprehensive coverage of studies with registered Digital Object Identifier (DOI) independently of commercial database selection criteria, with advantages for regional, non-Anglophone, and recently established journals⁽¹⁶⁾. Crossref was used in parallel as a cross-check and to resolve the founding-issue registration described below^(17,18).

All articles published by the JFA were obtained from OpenAlex using the journal's current ISSN (2675-2980). This search returned 416 records, each containing the article's title, authors, institutional affiliations, country of authorship, year, volume and issue, citation count, and open access status.

Throughout this paper, journal issues are abbreviated as volume-issue pairs (for example, V14 N2 = volume 14, issue 2, published August 2020).

The 22 articles published in the first issue of the unified JFA (Volume 14, Issue 1, April 2020—hereinafter V14 N1) did not appear in the initial search. Direct inspection of their DOIs revealed that these articles had been registered in Crossref under the predecessor journal's ISSN (2595-1459, *Scientific Journal of the Foot & Ankle*) rather than the current JFA ISSN. This transitional registration coincided with the formal unification of the journal in April 2020. All later issues, starting from volume 14, issue 2 (V14 N2, August 2020), use the current ISSN.

To recover these 22 missing articles, a separate Crossref search was performed using the predecessor ISSN. The bibliographic and citation data of each were then retrieved from OpenAlex by direct lookup of their individual DOIs. This dual-ISSN issue is itself a methodological observation about how regional journals appear in international databases during editorial transitions, and is discussed further below.

Inclusion and exclusion criteria

The final analysis comprised 334 peer-reviewed research articles, after excluding 89 out-of-scope records published in 2026 (79 conference abstracts from a meeting supplement and 10 articles from the first 2026 issue, all outside the 2020-2025 study period), reassigning 16 articles affected by the continuous-publication transition (with no change in total count), and removing 15 non-research items (14 editorials and 1 tribute). The complete identification, screening, cleaning, and inclusion process is summarized in Figure 1.

Document-type classification

Article category (Original Article, Case Report, Special Article, Technical Tip, Systematic Review, and Review) was determined by manual review of the journal's Table of Contents for each issue, since the OpenAlex 'work_type' field does not reliably distinguish among the journal's categories.

Author normalization

Author names in the source records showed minor variations in accents, capitalization, and spacing across articles. To avoid counting the same author as multiple entries, all author names were normalized: diacritical marks were removed, all letters were converted to lowercase, and extra whitespace was collapsed. This produced a comparison key used to group different display forms of the same author. Within each group, the most frequent display form in the original data was retained as the canonical name shown in the results.

Outcome measures

Annual production was computed by year and by volume/issue^(1,19).

Authorship metrics included the total number of unique authors after de-duplication, the mean and median number of authors per article, the proportion of single-authored articles,

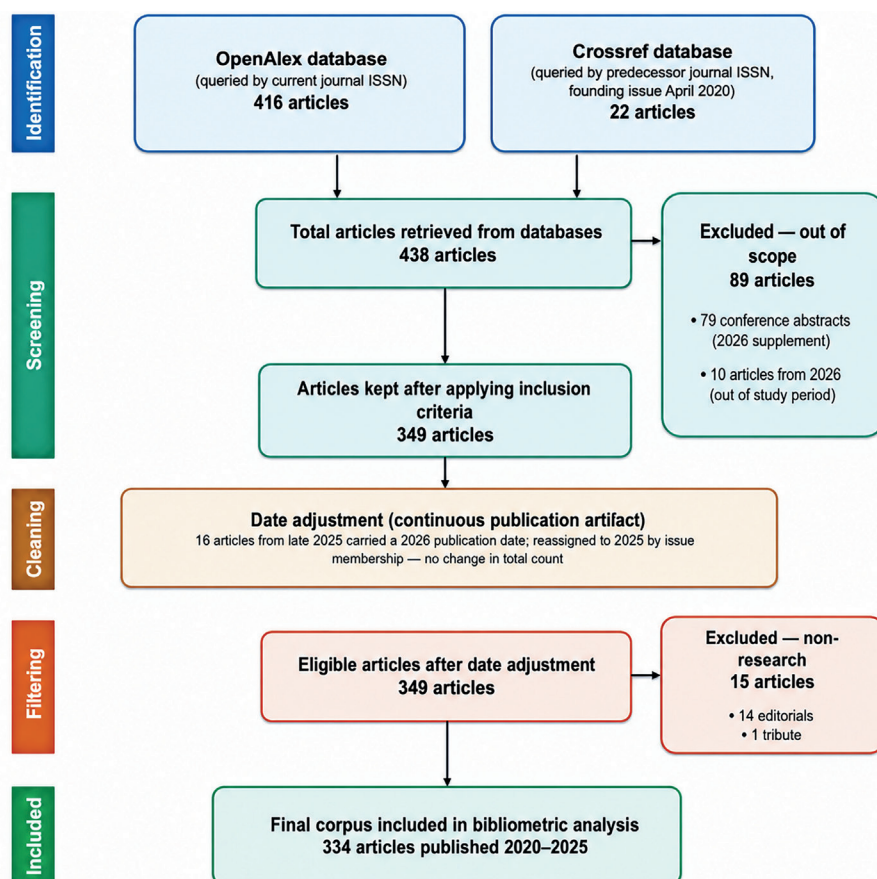


Figure 1. Identification, screening, cleaning, filtering and inclusion of the bibliographic articles.

Records were identified from two complementary database queries (OpenAlex under the current JFA ISSN; Crossref under the predecessor ISSN for the founding-issue artifact). After out-of-scope exclusion (meeting abstracts and 2026 articles), date reassignment for the continuous-publication transition, and non-research filtering (editorials and tributes), 334 peer-reviewed research articles remained for bibliometric analysis.

and a ranking of the most active authors based on their leadership role in each article. For this ranking, one credit was assigned to the first author and one to the last author of each article; if the same person occupied both positions, the article contributed a single credit. This approach reflects the convention in clinical research where first authorship indicates the lead investigator responsible for the study and last authorship indicates the senior or supervising role, whereas middle-author positions carry a weaker signal of intellectual leadership⁽²⁰⁻²²⁾.

Geographic distribution was computed at two levels: (i) per article, defined as the country most frequently represented among the article's authors, and (ii) per author, summing all author appearances by country across the total. Institutional ranking was computed using the whole-counting method (also called full counting), in which an institution received one credit per article in which it appeared as an affiliation of any author, regardless of authorship position; multiple authors

from the same institution within a single article did not inflate the institution's count. This is the standard method in journal-level bibliometric studies and the default of Web of Science and Scopus⁽²³⁻²⁵⁾.

Citation impact was characterized by the cumulative citation count, the mean and median citations per article, the citation distribution, the most-cited articles, and the journal h-index (defined as the largest number h such that h articles received at least h citations each)⁽²⁶⁻²⁹⁾. International collaboration was defined as an article with co-authors from two or more countries⁽³⁰⁻³²⁾.

Software and reproducibility

Data retrieval and analysis were performed in R (version 4.5.2; R Foundation for Statistical Computing, Vienna, Austria), using jsonlite for parsing bibliographic records from the OpenAlex and Crossref databases; dplyr and tidyr

for data manipulation; and stringi for text normalization and author name de-duplication. No inferential statistical testing was performed, as the study is descriptive of an enumerable population.

Results

Production and document-type composition

A total of 334 peer-reviewed research articles were included, with a mean of 56 articles per year (range 31-73) (Table 1). Original articles accounted for 68.9% of the total, followed by case reports (12.6%), special articles (8.4%), technical tips (4.2%), systematic reviews (3.3%), and narrative reviews (2.7%).

Authorship structure

The articles were authored by 1,037 unique authors after de-duplication. The mean number of authors per article was 5.2 (median 5; range 1-14), and 17 articles (5.1%) were single-authored.

Author productivity was assessed by ranking authors according to their number of first-author or last-author appearances (Table 2). César de César Netto led the ranking with 15 leadership appearances (1 as first author, 14 as last), followed by Alexandre Leme Godoy-Santos with 14 (3 first, 12 last) and Eli Ávila Souza Júnior with 10 (5 first, 8 last). The

top 10 included authors from Brazil, the United States, South Africa and Argentina.

Geographic and institutional distribution

Authorship by country is presented in Table 3. Brazil was the predominant country in most articles, followed by the United States and by other Latin American, European, Asian and African countries.

Institutional ranking by whole counting is presented in Table 4. Nine of the top 10 institutions were based in Brazil; the remaining one was the University of Iowa.

Citation impact

The 334 articles accumulated 272 citations, with a journal h-index of 6. The distribution was skewed, with 214 articles (64.1%) having received zero citations at the data extraction date. The 10 most cited articles are listed in Table 5.

International collaboration

Articles with co-authors from two or more countries represented 10.5% of the total over the study period, ranging from 8.2% to 14.3% across individual years. The most frequent country pairings were Brazil-United States, Brazil-Argentina, Brazil-Spain, and Argentina-Chile.

Table 1. Annual production by year and document type (n = 334, 2020-2025)

Year	Articles	Original	Case Rep.	Special	Tech. Tip	Syst. Rev.	Review
2020	56	39	9	5	1	0	1
2021	55	44	5	3	2	1	1
2022	60	44	8	4	1	3	1
2023	31	20	7	1	1	2	1
2024	59	37	10	5	5	2	1
2025	73	46	3	10	4	3	4
Total	334	230	42	28	14	11	9

Table 2. Top 10 authors ranked by leadership appearances (first or last author), 2020-2025

#	Author	Country	First + Last	As first	As last
1	César de César Netto	US	15	1	14
2	Alexandre Leme Godoy-Santos	BR	14	3	12
3	Eli Ávila Souza Júnior	BR	10	5	8
4	Nacime Salomão Barbachan Mansur	US	7	2	5
5	Daniel Baumfeld	BR	7	4	3
6	Paulo N. F. Ferrao	ZA	6	1	5
7	Gustavo Araújo Nunes	BR	6	3	3
8	Tiago Baumfeld	BR	6	3	3
9	Juan Drago	AR	5	0	5
10	Marcelo Pires Prado	BR	5	0	5

Note. "First + Last" counts the number of articles in which the author appeared as first or last author; if the same author occupied both positions in an article, that article contributed a single credit.

Discussion

The findings of this analysis position JFA as the principal Ibero-American outlet for foot and ankle research, consistent with a well-documented pattern in Latin American orthopedic publishing in which regional journals serve as the

primary vehicle for local researchers. Latin American countries account for approximately 1% of global orthopedic publications, with Brazil and Argentina historically dominating the most cited regional contributions⁽³³⁾. In parallel, 38.4% of Latin American orthopedic articles are published in regional

Table 3. Top 10 contributing countries, 2020-2025

#	Country	Articles (predominant)	% of corpus	Author appearances
1	Brazil	185	55.4%	930
2	United States	34	10.2%	223
3	Argentina	20	6.0%	101
4	Spain	13	3.9%	39
5	Chile	10	3.0%	50
6	India	8	2.4%	33
7	South Africa	8	2.4%	24
8	Mexico	7	2.1%	30
9	Portugal	6	1.8%	22
10	Colombia	4	1.2%	12

Note. Predominant country of authorship could not be resolved for 14 articles (4.2%).

Table 4. Top 10 contributing institutions, 2020-2025

#	Institution	Country	Articles
1	Universidade Federal de São Paulo	BR	23
2	Hospital Israelita Albert Einstein	BR	21
3	Hospital das Clínicas FMUSP	BR	18
4	University of Iowa	US	16
5	Hospital Felício Rocho	BR	15
6	Universidade Federal de Minas Gerais	BR	13
7	Hospital do Servidor Público Municipal (SP)	BR	10
8	Mater Dei Hospital	BR	9
9	Universidade de São Paulo	BR	9
10	Universidade Federal de Alfenas	BR	9

Note. Whole counting; any author affiliation, deduplicated per article

Table 5. Top 10 most cited articles, 2020-2025

#	Title	First author/last author	Volume/Issue	Citations
1	Lapicotton technique in progressive collapsing foot deformity	de César Netto/Mansur	V14 N3 2020	10
2	What do we know about hallux valgus pathogenesis?	Ferreira/Monteagudo	V14 N3 2020	9
3	Lateral ankle stabilization with a polyester fiber construct	Hermida Galindo/Torres Gómez	V14 N1 2020	9
4	Glomus tumors in the foot	Workman/Ferrao	V14 N2 2020	7
5	Automated 3D distance and coverage mapping of hallux valgus	Mendes de Carvalho/de César Netto	V16 N1 2022	7
6	Reliability of coronal plane rotation in the medial column	Dibbern/de César Netto	V15 N3 2021	7
7	Hallux valgus measurements using weight-bearing CT	Braza/Nery	V15 N3 2021	6
8	Minimally invasive bunionette treatment	de Vete Lima/Nunes	V14 N2 2020	6
9	Posterolateral approach: early complications	Tavares/Zambelli	V14 N2 2020	5
10	Acute retrograde TTC nailing in osteoporotic fractures	Herrera-Pérez/País-Brito	V14 N2 2020	5

journals, and 46.6% appear in journals with an impact factor below 1⁽³⁴⁾, a pattern JFA replicates by combining a strong Brazilian anchor with meaningful contributions from Argentina, Spain, Chile, Mexico, Portugal, and Colombia. Structural underrepresentation reinforces this dynamic, since only 2.62% of editorial board members across major foot and ankle journals originate from Latin America and the Caribbean⁽³⁵⁾, which underscores the strategic value of a journal whose editorial governance is fully regional.

The leadership analysis based on first and last authorship positions shows that JFA is driven by a small group of highly active senior researchers. Studies of orthopedic journals in low- and middle-income countries have consistently shown that over 92% of articles retain first or last authorship by local researchers, although international collaboration significantly reduces local leadership rates⁽³⁶⁾. The presence of senior authors in JFA from Argentina, South Africa, Brazil, Chile and Spain suggests that the journal successfully preserves regional research leadership while participating in international collaborations. The observed mean number of authors per article and the increase in systematic reviews mirror trends recently documented in other subspecialty orthopedic journals⁽³⁷⁾, pointing to a broader shift toward multi-author collaborative research and higher-evidence document types.

The modest citation footprint of JFA, with a mean of 0.81 citations per article and a journal h-index of 6, is consistent with the profile of a young journal not yet indexed in Scopus, Web of Science, or PubMed/MEDLINE. Journal prestige and indexation status are the strongest predictors of citation rate, exceeding the influence of study quality⁽³⁸⁾. The median citation lag in medical journals is approximately 7.5 years⁽³⁹⁾, and citation peaks in surgical literature occur around 6.25 years after publication⁽⁴⁰⁾, well beyond the five-year observation window of this analysis. Since over half of the JFA articles were published in 2024 or later, citation accrual remains in an early phase. The observed increase in systematic reviews across the study period is relevant in this context because meta-analyses and systematic reviews are cited more frequently than other study designs⁽⁴¹⁾, which suggests that continued editorial emphasis on higher-evidence formats should progressively improve citation impact. Achieving indexation in Scopus and PubMed Central would be expected to substantially accelerate this trajectory.

The Diamond Open Access model of JFA, in which articles are published without author-side charges, is a defining

feature of its editorial identity. Article processing charges in medical journals typically range from USD 3,500 to 4,850⁽⁴²⁾ and can exceed USD 10,000 in high-impact venues⁽⁴³⁾, creating a substantial barrier for researchers from low- and middle-income regions where Article Processing Charges (APCs) exacerbate global inequities in scientific publishing⁽⁴⁴⁾. By removing this barrier, JFA operates as an explicit equity mechanism for regional authors and contributes to the bibliodiversity of independent, non-commercial scientific publishing⁽⁴⁵⁾.

The founding issue of the unified JFA was registered in Crossref under the predecessor journal's ISSN, reflecting variable metadata completeness across editorial platforms⁽⁴⁶⁾ and highlighting the need for dual-ISSN retrieval to avoid articles undercount in journals with editorial transitions. OpenAlex was chosen as the primary source because it indexes 34,217 open access journals compared with 7,351 in Scopus and 6,157 in Web of Science⁽⁴⁷⁾, providing broader coverage of regional and non-English literature⁽⁴⁸⁾.

This study has several limitations. Approximately 4% of articles had insufficient affiliation data to assign a predominant country reliably. The journal h-index, while widely used, systematically disadvantages young journals with fewer indexed publications and short observation windows⁽⁴⁹⁾. The leadership analysis treats first and last authorship as equally weighted indicators, whereas last authorship typically carries a stronger signal of senior responsibility in clinical research; the disaggregated columns of Table 2 allow readers to apply their preferred weighting. Finally, this study is descriptive and does not include comparative benchmarking against peer journals or assessment of editorial workflow metrics such as time-to-publication or rejection rates, which would require access to internal data not available in public bibliographic databases.

Conclusion

The Journal of the Foot & Ankle has consolidated over its first five years as the principal Ibero-American outlet for foot and ankle research, with a Brazilian-anchored yet regionally inclusive authorship, a sustained Diamond Open Access model, and an early citation footprint consistent with its pre-indexation stage. Continued progression toward indexation in Scopus and PubMed/MEDLINE, together with the observed editorial shift toward higher-evidence document types, is expected to further strengthen the international visibility and impact of the journal.

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Original Article

Clinical outcomes following interpositional arthroplasty for advanced hallux rigidus: A retrospective case series

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Abstract

Objective: To evaluate clinical and functional outcomes following interpositional arthroplasty in a Brazilian cohort.

Methods: This retrospective case series included 10 patients with grade III-IV hallux rigidus (HR) treated between January and September 2025. All procedures were performed by a single experienced foot and ankle surgeon. Inclusion criteria were failure of at least six months of conservative treatment. Exclusion criteria included diabetes mellitus, rheumatoid arthritis, and prior first metatarsophalangeal joint (MTPJ) surgery. Outcomes were assessed using the visual analog scale (VAS) and the American Orthopaedic Foot & Ankle Society (AOFAS) score preoperatively and at four months postoperatively. Statistical analysis included descriptive statistics, the Shapiro-Wilk test, and the Wilcoxon signed-rank test, with significance set at $p < 0.05$.

Results: The cohort was predominantly female (90.00%, 9/10), with a mean age of 58.700 ± 11.180 years. All patients achieved greater than 30° of first MTPJ range of motion at final follow-up. Radiographs demonstrated adequate bone resection and preservation of joint space. Pain improved progressively, with median VAS decreasing from 7.000 (IQR 6.500-8.000) preoperatively to 1.500 at four months (IQR 0.000-2.000). Functional outcomes improved significantly, with median AOFAS increasing from 52.000 (IQR 42.000-66.750) preoperatively to 84.000 (IQR: 84.000-99.000) at final follow-up.

Conclusion: Interpositional arthroplasty resulted in significant improvements in pain and function while preserving joint motion in patients with advanced hallux valgus. This technique represents a viable motion-preserving alternative for selected patients who wish to avoid arthrodesis.

Level of evidence IV; Retrospective Study.

Keywords: Metatarsophalangeal joint; Hallux rigidus; Arthroplasty; Treatment outcome.

Introduction

Hallux rigidus (HR) is among the most common arthritic conditions of the foot, affecting approximately 2.5% of individuals over 50 years of age^(1,2), with a higher prevalence in females^(3,4). It is a progressive degenerative disorder of the first metatarsophalangeal joint (MTPJ), characterized by joint stiffness and a gradual loss of motion, particularly impairing the push-off phase of gait. As the disease progresses, it can result in significant pain, functional limitation, and reduced quality of life⁽⁵⁾. The MTPJ is subjected to substantial me-

chanical loads, with forces reaching approximately 119% of body weight during normal gait⁽¹⁾.

The HR etiology is multifactorial, involving mechanical factors, genetic predisposition, and, in some cases, prior trauma⁽⁶⁾. Patients with osteoarthritis in other joints, such as gonarthrosis, have an increased risk of developing HR. In addition, individuals with gout, hallux valgus, or inflammatory joint diseases, such as rheumatoid arthritis, represent relevant risk groups, although the degenerative form remains the most prevalent^(2,6).

Study performed at the Departamento de Ortopedia e Traumatologia, Centro de Traumatologia do Esporte, Universidade Federal de São Paulo, São Paulo, SP, Brazil.

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Initial management of early-stage HR includes activity modification, orthotics, analgesics, and corticosteroid injections^(7,8). When conservative treatment fails, numerous viable operative techniques exist to treat HR, such as cheilectomy, resection arthroplasty, interpositional arthroplasty, and arthrodesis^(4,9,10). In advanced stages of the disease (grades III and IV), MTPJ arthrodesis is considered the gold-standard treatment for HR, providing long-lasting pain relief, a high rate of bone consolidation, and high functional satisfaction, especially after failure of conservative treatment^(11,12). However, the loss of joint motion following arthrodesis has led to growing interest in motion-preserving alternatives^(13,14).

Interpositional arthroplasty has emerged as an alternative for advanced HR, aiming to preserve joint motion by placing a biologic spacer, particularly in active patients who wish to avoid permanent loss of mobility⁽¹⁵⁾. This technique preserves both motion and bone stock and has evolved since its initial description by Hamilton et al. (1997)⁽¹⁶⁾ with modifications incorporating capsular tissue, local tendons, or biologic matrices. Among these, the modified oblique Keller capsular interpositional arthroplasty (MOKCIA), described by Johnson and McCormick (2014)⁽¹⁴⁾, has gained attention for its ability to maintain joint stability while preserving flexor tendon function.

Recent systematic reviews have demonstrated improvements in functional outcomes and range of motion following interpositional arthroplasty at mid-term follow-up⁽¹⁷⁾. Additionally, a systematic review including 20 studies and 539 feet reported that 90% of patients experienced significant clinical improvement at a mean follow-up of 4.5 years, with only 3.8% requiring revision surgery⁽¹⁷⁾.

However, there remains a paucity of studies evaluating outcomes within a single surgical team and at a national level. Therefore, this study aims to assess the effects of

interpositional arthroplasty on pain, function, and alignment, as measured by the visual analog scale (VAS) and the American Orthopaedic Foot & Ankle Society (AOFAS) score.

Methods

This is a retrospective case series study comprising 10 patients diagnosed with grade III or IV HR who underwent surgery between January and September 2025 at a public hospital. All patients completed a 4-month postoperative follow-up, which corresponded to the final study assessment. All procedures and follow-up evaluations were performed by a single foot and ankle specialist surgeon with more than five years of experience in foot and ankle surgery.

The study was approved by the Institutional Review Board. The guidelines established by Resolution No. 674/2022 of the National Health Council, which regulates research involving human beings in Brazil, were followed. All participants signed the Informed Consent Form (ICF).

All consecutive eligible patients with HR refractory to conservative treatment for at least six months who were treated during the study period were included. Exclusion criteria included diabetes mellitus, rheumatoid arthritis, and previous MTPJ surgery.

Indications for interpositional arthroplasty were based on the criteria described by Hamilton et al.⁽¹⁶⁾ and included severe HR with less than 10° of range of motion (grades III and IV), as confirmed by clinical and radiographic evaluation. On physical examination, patients demonstrated marked limitation of motion (particularly dorsiflexion), pain, and enlargement of the MTPJ. Anteroposterior and lateral radiographs showed near-complete joint space obliteration and extensive periarticular osteophyte formation (Figure 1).

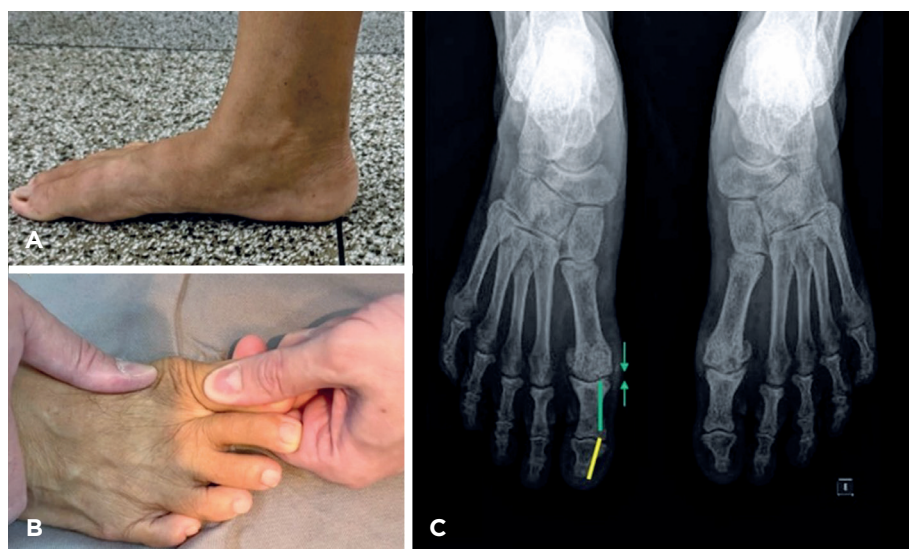


Figure 1. Clinical and radiographic evaluation of hallux rigidus. (A) Lateral view showing enlargement of the first metatarsophalangeal joint. (B) Physical examination demonstrating pain and marked limitation of motion, particularly dorsiflexion. (C) Anteroposterior and lateral radiographs showing near-complete joint space obliteration with extensive periarticular osteophyte formation.

Surgical technique

The procedure was performed in the operating room under spinal anesthesia. Potential sources of bias were minimized by including consecutive eligible patients, using standardized surgical and postoperative protocols, and performing all procedures under the supervision of a single experienced surgeon. However, given the retrospective design, residual measurement bias inherent to medical record data cannot be fully excluded. A dorsomedial incision was made over the MTPJ to expose the capsule. A U-shaped capsular flap with a distal base was created. Soft tissues were carefully released, including partial detachment of the dorsal capsule and

selected fibers of the plantar plate and flexor hallucis brevis. A standard cheilectomy was performed, with resection of approximately 25%-30% of the dorsal aspect of the first metatarsal head using a sagittal saw. The base of the proximal phalanx was resected approximately 0.3 cm distal to the MTPJ. The extensor hallucis brevis tendon was transected to allow adequate mobilization, and the capsular flap together with the tendon was interposed beneath the base of the proximal phalanx and secured using nonabsorbable sutures. Postoperatively, patients were allowed immediate weight-bearing as tolerated with a rigid-soled postoperative shoe for six weeks, followed by a transition to regular footwear. Early mobilization was encouraged (Figures 2 and 3).

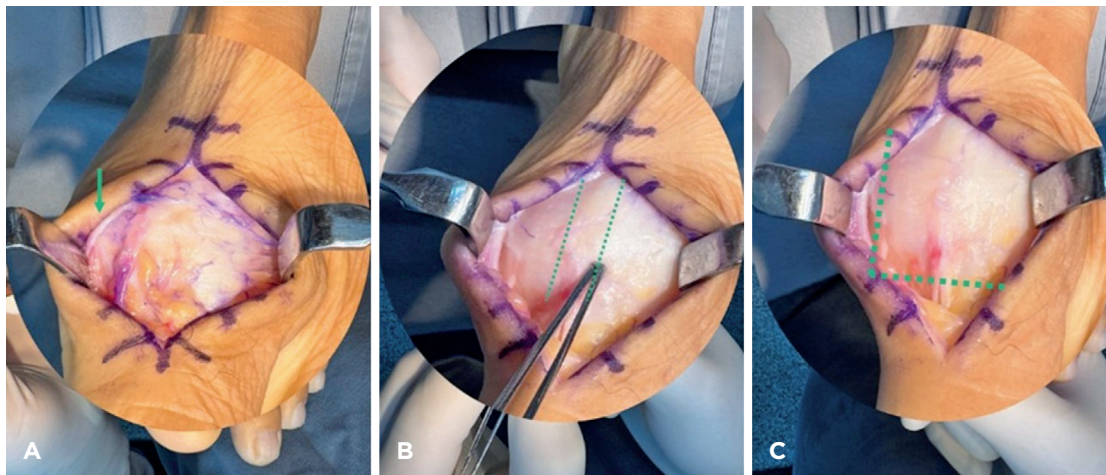


Figure 2. Intraoperative steps of interpositional arthroplasty for hallux rigidus. (A) Identification of the dorsomedial cutaneous nerve (green arrow) on the medial aspect of the foot. (B) Identification and dissection of the extensor hallucis longus tendon (green dotted line) from the joint capsule. (C) Surgical exposure of the first metatarsophalangeal joint through capsular dissection, with separation of the capsule from the extensor hallucis brevis tendon, facilitating preparation for interpositional arthroplasty.

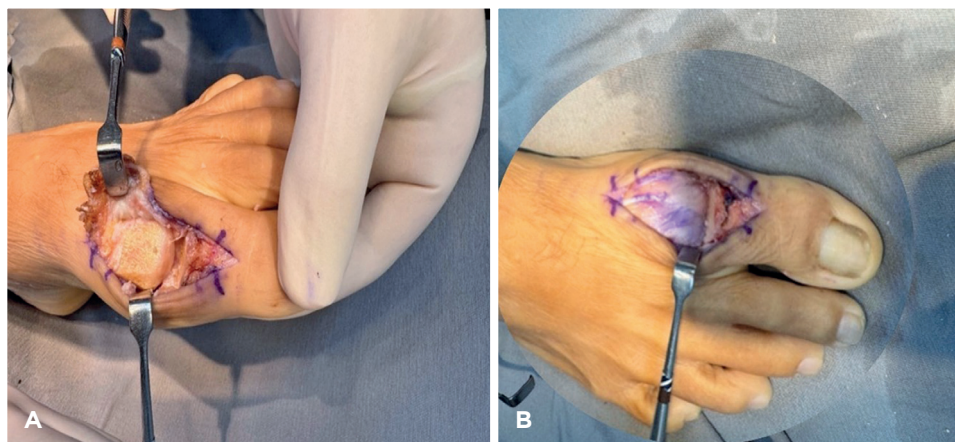


Figure 3. Interpositional Arthroplasty for hallux rigidus. (A) Cheilectomy with resection of approximately 25%-30% of the dorsal aspect of the first metatarsal head, followed by resection of the base of the proximal phalanx approximately 0.3 cm distal to the first metatarsophalangeal joint. (B) Clinical image demonstrating capsular interposition.

Patient-reported outcomes

Physical function was evaluated using the AOFAS. Preoperative AOFAS scores were collected from patients' medical histories. The AOFAS consists of three subscales: pain, function and alignment, and includes a total of nine items. The minimum score is 0 points (indicating severe pain and impairment), the maximum score is 100 points (no impairment). Pain was evaluated using the VAS from 0 to 10 (0: no pain, 10: worst possible pain). The pain VAS was obtained preoperatively and at five postoperative follow-up time points.

Data collection and statistical analysis

Data were extracted from complete medical records with no missing variables for the outcomes of interest. The study included all consecutive eligible patients treated during the study period; therefore, no formal sample size calculation was performed. The database was constructed using Excel. Descriptive analysis was performed using absolute (n) and relative (%) frequencies for categorical variables. Continuous variables are presented as mean ± standard deviation or

median (interquartile range, IQR), depending on the data distribution. Data distribution was assessed using the Shapiro-Wilk test. The Wilcoxon signed-rank test was used for comparisons between related samples, and exact p-values were reported for non-parametric comparisons. Because this was a descriptive retrospective case series without a comparison group, no adjustment for potential confounding variables was performed. GraphPad Prism version 11.0.0 (GraphPad Software, Boston, MA, USA) was used for statistical analyses, with a significance level of $p < 0.05$.

Results

Ten patients were included in the final analysis. The sample was predominantly female (90.00%; 9 females and 1 male). Age, weight, and height (mean ± SD) were 58.700 ± 11.180 years, 73.900 ± 8.103 kg, and 1.710 ± 0.049 m, respectively. Regarding the affected side, five participants underwent right-sided surgery and five underwent left-sided surgery (Table 1). Radiographs were reviewed before surgery, immediately after surgery, and at the last follow-up appointment (Figure 4). The range of MTPJ in all patients was greater than 30° .

Table 1. Demographic factors of 10 patients undergoing interpositional arthroplasty for the treatment of hallux rigidus.

Variables	Mean	SD	95% CI of the mean
Age (years)	58.700	11.180	50.71 to 66.69
Weight (kg)	73.900	8.103	68.10 to 79.70
Height (m)	1.710	0.049	1.675 to 1.745
BMI (kg/m²)	25.260	2.248	23.480 to 27.030
Gender, n (%)			
Female	9 (90%)	-	-
Male	1 (10%)	-	-
Operated side, n (%)			
Right	5 (50%)	-	-
Left	5 (50%)	-	-

BMI: Body mass index; CI: Confidence interval; SD: Standard deviation.

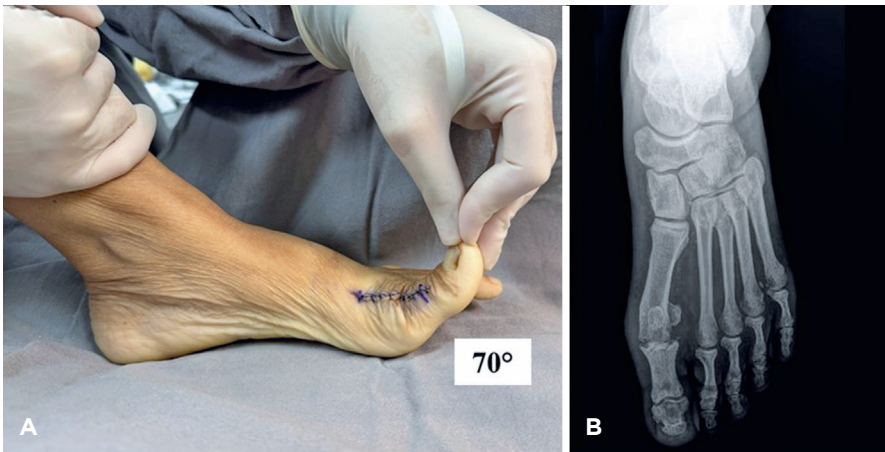


Figure 4. Assessment of range of motion and radiography after surgery at the time of the last follow-up. (A) Clinical assessment of the range of motion of the first joint. (B) Anteroposterior radiograph demonstrating bone resection level and preserved joint space. Observe the relatively equal lengths of the first and second metatarsals.

Pain and functional outcomes improved progressively after surgery. Preoperatively, the median VAS score was 7.000 (IQR 6.500-8.000). At one week postoperatively, it decreased to 5.000 (IQR 3.500-5.500), a statistically significant reduction compared with baseline ($p = 0.035$). At three weeks, the median was 4.500 (IQR 2.750-6.250), remaining lower than preoperative values ($p = 0.014$). Further reductions were observed at six weeks (median 3.000, IQR 1.500-4.000), two months (median 2.500, IQR 0.000-3.000), and four months (median 1.500, IQR 0.000-2.000), demonstrating continuous improvement in pain outcomes over time (Table 2).

Preoperatively, the median AOFAS score was 52.000 (IQR 42.000-66.750). Improvement was observed as early as one week (median 68.000, IQR 64.750-79.250; $p = 0.0322$). At three weeks, the median score increased to 70.000 (IQR 66.000-84.000), representing a significant improvement compared with baseline values. At six weeks, two months, and four months, median scores reached 84.000, indicating continuous functional recovery, with statistically significant differences compared with preoperative values at nearly all time points (Table 3).

One patient (10%) required revision surgery during the follow-up period due to persistent symptoms. No other postoperative complications were observed.

Discussion

This study demonstrated that interpositional arthroplasty for HR resulted in significant early and sustained improvements in pain and function in a Brazilian cohort, with all procedures performed by a single experienced foot and ankle surgeon,

ensuring technical consistency across cases. Both VAS and AOFAS scores improved progressively from the immediate postoperative period through the final follow-up (4 months), supporting this technique as an effective motion-preserving option for selected patients.

Pain reduction was clinically relevant and early, with median VAS decreasing from 7.000 (IQR 6.500-8.000) preoperatively to 5.000 (IQR 3.500-5.500) at one week ($p = 0.035$), 4.500 (IQR 2.750-6.250) at three weeks ($p = 0.014$), and reaching 1.500 (IQR 0.000-2.000) at four months.

This represents an overall reduction of approximately 79% in pain scores. The early and sustained improvement is consistent with a recent systematic review showing that interpositional procedures provide reliable short-term pain relief in HR⁽¹⁸⁾ and with a retrospective study⁽¹⁹⁾. Furthermore, Vulcano et al.⁽²⁰⁾ reported results similar to ours, with a mean VAS score decreasing from 7.9 preoperatively to 1.8 postoperatively at a mean follow-up of 11.3 years, suggesting that these outcomes may be sustained over time.

Functional outcomes followed a similar trajectory. Preoperatively, the median AOFAS score was 52.000 (IQR 42.000-66.750). Improvement was observed as early as one week (median 68.000, IQR 64.750-79.250; $p = 0.0322$). At three weeks, the median score increased to 70.000 (IQR 66.000-84.000), representing a significant improvement compared with baseline values. Scores remained stable thereafter, with a median score of 84.000 at final follow-up. This represents an overall gain of approximately +32 points, which is consistent with the benefits of interpositional arthroplasty shown in systematic review studies^(9,18,21). The early functional recovery observed in this cohort is particularly relevant, as most

Table 2. Evaluation of the visual analog scale after interpositional arthroplasty for hallux rigidus.

Time	Mean $\pm$ SD	Median	IQR (Q1-Q3)	p1	p2	p3	p4	p5
Pre-operative	7.000 $\pm$ 1.491	7.000	(6.500-8.000)	—				
1 Week	4.500 $\pm$ 2.270	5.000	(3.500-5.500)	0.035	—			
3 Weeks	4.200 $\pm$ 2.250	4.500	(2.750-6.250)	0.014	0.523	—		
6 Weeks	2.600 $\pm$ 1.570	3.000	(1.500-4.000)	0.009	0.020	0.035	—	
2 Months	1.800 $\pm$ 1.390	2.500	(0.000-3.000)	0.005	0.008	0.013	0.065	—
4 Months	1.300 $\pm$ 1.050	1.500	(0.000-2.000)	0.004	0.008	0.008	0.021	0.089

SD: Standard deviation. Values are presented as mean $\pm$ standard deviation and median (interquartile range, IQR). P-values were obtained using the Wilcoxon signed-rank test for paired comparisons. p1 compares each follow-up time point with preoperative values; p2 with 1 week; p3 with 3 weeks; p4 with 6 weeks; and p5 with 2 months. Bold values indicate statistical significance ($p < 0.05$).

Table 3. Evaluation of American Orthopaedic Foot & Ankle Society scores after interpositional arthroplasty for hallux rigidus.

Time	Mean $\pm$ SD	Median	IQR (Q1-Q3)	p1	p2	p3	p4	p5
Pre-operative	56.100 $\pm$ 14.890	52.000	(42.000-66.750)	—				
1 Week	69.700 $\pm$ 14.890	68.000	(64.750-79.250)	0.032	—			
3 Weeks	73.700 $\pm$ 8.840	70.000	(66.000-84.000)	0.024	0.035	—		
6 Weeks	83.300 $\pm$ 11.450	84.000	(73.750-96.000)	0.005	0.005	0.014	—	
2 Months	87.200 $\pm$ 11.650	84.000	(79.750-99.000)	0.005	0.005	0.008	0.062	—
4 Months	90.000 $\pm$ 7.970	84.000	(84.000-99.000)	0.005	0.005	0.005	0.031	0.345

SD: Standard deviation. Values are presented as mean $\pm$ standard deviation and median (interquartile range, IQR). P-values were obtained using the Wilcoxon signed-rank test for paired comparisons. p1 compares each follow-up time point with preoperative values; p2 with 1 week; p3 with 3 weeks; p4 with 6 weeks; and p5 with 2 months. Bold values indicate statistical significance ($p < 0.05$).

patients were physically active and motivated to preserve joint motion, a key factor in surgical decision-making for HR. In this context, motion-preserving procedures may offer a distinct advantage over arthrodesis, especially in individuals with higher functional demands in daily and recreational activities^(18,19,21).

Preservation of motion is one of the main advantages of interpositional arthroplasty. In this series, all patients achieved greater than 30° of MTPJ at final follow-up, which has been associated with improved gait mechanics^(9,19). Maintenance of mobility has been consistently reported in recent literature and is particularly relevant in active populations, in whom loss of mobility may result in compensatory overload of adjacent joints^(9,16,18,20).

Complication rates were low, with only one patient requiring revision surgery (10%). This is consistent with recent systematic reviews reporting acceptable complication profiles, with metatarsalgia as the most frequent adverse event^(17,19).

Arthrodesis remains the gold standard for advanced HR due to its predictable pain relief and durability⁽²²⁾. However, it eliminates motion and may limit footwear options and higher-demand activities. In contrast, interpositional arthroplasty offers a motion-preserving alternative, which may be particularly advantageous for younger or more active patients, or those who prioritize joint mobility. Comparative studies suggest that while arthrodesis may provide more consistent long-term pain control, interpositional techniques can achieve satisfactory outcomes while preserving function and motion^(18,19,21,23).

Long-term comparative data also support interpositional techniques as a motion-preserving alternative. A recent study demonstrated similar pain, satisfaction, and functional outcomes between interpositional arthroplasty and arthrodesis at over 10 years of follow-up, with maintained joint motion and no significant differences in plantar pressure. These findings suggest that interpositional arthroplasty may achieve outcomes comparable to those of arthrodesis in selected patients while preserving mobility⁽¹⁴⁾.

The demographic profile of this cohort (90% female, mean age 58.700 ± 11.180 years) is consistent with the known epidemiology of HR^(16,19,23,24). The homogeneous sample and single-surgeon design improve internal validity, but may limit external generalizability.

This study has several limitations. Its retrospective design, small sample size, and short follow-up period (4 months) limit conclusions regarding the long-term durability of the procedure, late complications, symptom recurrence, and revision rates. In addition, individual range of motion measurements were not consistently recorded throughout the postoperative follow-up, limiting the assessment of longitudinal changes in joint mobility. Although the single-surgeon approach improves technical consistency, it may reduce external applicability. The absence of a control group, particularly arthrodesis cases, also limits comparative interpretation.

Despite these limitations, the present study supports interpositional arthroplasty as a viable surgical option for HR, providing significant early improvements in pain (VAS: 7.000 to 1.500) and function (AOFAS: 52.000 to 84.000), while preserving joint motion in a population with higher functional demands than those typically reported in the literature. To our knowledge, this study is among the first Brazilian case series to evaluate interpositional arthroplasty for advanced HR using standardized patient-reported outcome measures and a single-surgeon protocol. The fact that this study was conducted in a Brazilian population and the single-surgeon design enhances the internal consistency of the findings, as there is a scarcity of published data on interpositional arthroplasty in South American cohorts. In addition, no previous Brazilian case series that specifically evaluates interpositional arthroplasty for HR using standardized patient-reported outcome measures has been published in the indexed literature, highlighting the regional contribution of the present study. However, future prospective, randomized, multicenter, and comparative studies with longer follow-up are required to better define its role relative to established surgical treatments.

Conclusion

Dorsal capsular interpositional arthroplasty may represent a valuable surgical option for advanced HR, providing early improvements in pain and function while preserving joint motion throughout the 4-month follow-up period. These findings are consistent with the broader literature on interpositional techniques. However, higher-quality studies with longer follow-up are needed to better define its indications and long-term outcomes.

Authors' contribution: Each author contributed individually and significantly to the development of this article: FGC *(<https://orcid.org/0000-0002-9311-5661>) Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing of original draft, review & editing, Supervision; ISMC *(<https://orcid.org/0000-0002-6183-6667>) Investigation, Data curation, Validation, review & editing; GAC *(<https://orcid.org/0000-0002-6458-6317>) Investigation, Validation, Review & editing; TSM *(<https://orcid.org/0000-0003-4168-0981>) Formal analysis, Validation, Review & editing; ESM *(<https://orcid.org/0000-0002-8572-7764>) Investigation, Data curation, Writing and editing; LSF *(<https://orcid.org/0000-0001-6497-833X>) Formal analysis, Data curation, Visualization, Review and editing; NSBM *(<https://orcid.org/0000-0003-1067-727X>) Conceptualization, Methodology, Supervision, Validation, Review and editing; LFM *(<https://orcid.org/0000-0003-0318-2842>) Formal analysis, Validation, Review and editing. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) .

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Original Article

Radiographic morphometric analysis of cuboid bone in asymptomatic adult feet: Reference values and anatomical parameters

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Abstract

Objectives: To establish radiographic parameters of normality of the cuboid bone and to assist in therapeutic decisions in several diseases.

Methods: Five hundred and sixteen adult patients (516 feet) aged between 18 and 70 years were selected, distributed equally between sexes and without current or previous cuboid lesions. Foot radiographs at internal oblique incidence were performed and two parameters were evaluated. The first was the measurement of the alpha angle, formed between the distal and proximal articular surfaces of the cuboid, and the second was the ratio between the length of the lateral and medial walls.

Results: Radiographic parameters were evaluated, and the results by sex and age group were divided into groups (18 to 50 and 50 to 70 years). Alpha angle values in the general population ranged from 21.6° to 49.2°, with a mean of 35.62°, and differed by sex, with male patients showing a higher angle (35.11° x 36.13°). The ratio between the walls ranged from 0.37 to 0.69, with a mean of 0.52 and no sex differences.

Conclusion: The radiographic parameters studied may help define cuboid anatomy and guide the therapeutic approach to several foot injuries.

Level of Evidence III; Radiographic Descriptive Cross-Sectional Study.

Keywords: Cuboid bone; Radiography; Anatomy; Fractures; Trauma.

Introduction

The cuboid is a medial base pyramidal-shaped bone located in the lateral region of the midfoot. The medial facet articulates with the lateral cuneiform, the proximal facet with the calcaneus, and the distal facet articulates with the base of the 4th and 5th metatarsal bones. This bone provides an important connection between the hindfoot and forefoot and contributes to dorsoplantar movement and eversion/inversion of the foot, especially adaptation to irregular surfaces^(1,2).

Various pathological conditions may alter the shape and/or positioning of the cuboid. In Charcot's arthropathy, midfoot collapse can cause plantar displacement of the cuboid, sometimes below the foot support line, increasing the risk of callus formation and plantar ulceration⁽³⁾. Thus, anatomical knowledge of this bone and its relationships with other components of the foot is important for understanding these diseases and guiding the therapeutic approach.

Cuboid fractures can often be accompanied by other midfoot injuries, such as fractures and dislocations of the

Study performed at the Hospital Francisco José Neves, Hospital da Unimed de Belo Horizonte, Belo Horizonte, MG, Brazil.

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Lisfranc joints and fractures of the navicular and metatarsal bones⁽⁴⁻⁷⁾. Hermel and Cohen⁽⁸⁾ described the nutcracker fracture as an injury with a crushing pattern resulting from longitudinal compression of the lateral column of the foot through axial load with the foot in plantar flexion, with compression of the cuboid between the calcaneus and the lateral metatarsals. Other studies have shown a component of midfoot abduction, leading to compression of the lateral column and eventual injury of the medial column^(4,9).

A fundamental principle of treatment is evaluating the lateral column, as shown in internal oblique incidence and tomographic studies⁽¹⁰⁻¹²⁾. Shortening of this column can occur in cuboid compression fractures, leading to biomechanical changes in the midfoot and, consequently, deformities, pain, and instability^(6,13,14).

The primary objective of this study is to create radiographic parameters of normality of the cuboid bone. The secondary objective is to report whether these parameters differ by sex and age.

Methods

The study was approved by the Institutional Review Board. Due to the retrospective study design, the written Informed Consent Form (ICF) was not required. Consent to use patients' medical record data from the private institution where the study was conducted was obtained.

Type of study

The study used an observational cross-sectional design, and radiographs were used to diagnose other conditions without a cuboid lesion. Patients with traumatic and non-traumatic forefoot injuries between 18 and 70 years of age were included. Patients with combined hindfoot injuries and previous surgeries in this segment were excluded. Patients did not receive additional radiation for this study. It was decided not to include healthy patients to avoid unnecessary radiation exposure.

Radiographic technique

The internal oblique incidence of the feet was performed with the segment supported on a platform inclined at 30° to standardize foot positioning and avoid angular variation (Figure 1). Non-weight-bearing radiographs were obtained with the foot resting on the platform, the knee flexed to 90°, and the ankle flexed to 20°. The beam was centered at the base of the 5th metatarsal, and the tube was positioned 80 cm from the foot. The decision to perform non-weight-bearing radiographs is due to the predominance of patients with traumatic injury in the study. Initially, a pilot study was conducted with 58 adult patients (58 feet), aged 18 to 77 years (mean 54 years), of both sexes with no current or previous cuboid lesions, evaluated from November 2018 to January 2019. The objective of the pilot study was to obtain statistical parameters, including estimates of standard deviation (SD),

variability, and sample size. In total, the pilot study included 58 radiographs: 19 of male feet and 39 of female feet; 34 right feet and 24 left feet.

All radiographs were performed in a Siemens Multix 8 radiological set (model 7036374, Munich, Germany). The images were captured using a digital technology system, DR Shimadzu (model VIVIX-S4343VAW, Brazil). The evaluation and parameter measurements were performed in Vivace Connect MV software (version 2022.002.02.FTR, Teresópolis, Brazil).

In the radiographs, two parameters were measured: the first is the angle formed between the distal and proximal articular surfaces of the cuboid (Figure 2), which was defined by the



Figure 1. Foot radiography in internal oblique incidence on a platform with an inclination of 30° and image of the position of the foot.



Figure 2. Alpha angle measurement.

lines drawn connecting the medial-distal and lateral-distal (first line) and medial-proximal and lateral-proximal (second line) articular points, which are located outside the foot in the lateral region, named the alpha angle. The second is the ratio between the length of the lateral and medial cortical walls of the cuboid bone, which was performed by measuring the length of the lateral wall (which goes from the lateral-proximal point to the lateral-distal point of the bone) over the length of the medial wall (drawn from the medial-proximal point to the medial-distal point of the cuboid) (Figure 3). The parameters were created to obtain a more specific radiographic evaluation of the cuboid bone, with application for traumatic (especially fractures with a lateral compression pattern) and non-traumatic injuries.

The radiographs were evaluated by two orthopedists specialized in foot surgery with more than five years of experience and were recorded at two time points with a 30-day interval between evaluations.

Sample size calculation

Considering the characteristics and objectives of the study, the identification of the ideal sample was obtained through the calculations provided by Rosner⁽¹⁵⁾, which accounts for the confidence interval (CI), the power of the sample, the sample size ratio, the mean, and the SD of the populations to be studied. The sample was obtained with a 90% CI. The purpose of this interval was to identify a lower sample number that was within reality. In scientific studies, 95% CI is generally used. However, 90% CI is also accepted and statistically valid. For this, the following formulas were used:

$$n_1 = \frac{(\sigma_1^2 + \sigma_2^2 / \kappa)(z_{1-\alpha/2} + z_{1-\beta})^2}{\Delta^2}$$

$$n_2 = \frac{(\kappa * \sigma_1^2 + \sigma_2^2)(z_{1-\alpha/2} + z_{1-\beta})^2}{\Delta^2}$$

n_1 = sample size of group 1 (male individuals); n_2 = sample size of group 2 (female individuals); σ_1 = standard deviation of group 1; σ_2 = standard deviation of group 2; Δ = difference between means; κ = ratio n_2/n_1 ; $z_{1-\alpha/2}$ = two-tailed Z value, considering 95% and 90% CI; $z_{1-\beta}$ = sample power.

Some studies show that foot shape can change with aging, especially in relation to forefoot width⁽¹⁶⁾ and the fall of the longitudinal arch⁽¹⁷⁾. Thus, the parameters were measured in both sexes and in two age groups (18 to 50 years and 51 to 70 years). This division was based on changes observed in the study by Ansuategui Echeita et al.⁽¹⁶⁾, who showed changes in foot shape after the sixth decade of life.

The sample included 516 patients, equally distributed between males and females (258 patients in each group), and the images were obtained from radiographs taken between June 2022 and January 2023.

Statistical analysis

Initially, an exploratory analysis was performed using the Shapiro-Wilk test to assess whether the data follow a continuous distribution. Given the parametric nature of

these data, measures of central tendency were reported as the mean, SD, minimum, and maximum. For categorical variables, measures of frequency (n) and percentage (%) were calculated for each category. No multivariate analysis was performed for this study.

Reliability was evaluated through intra- and interobserver comparisons at 30-day intervals to ensure the consistency and stability of the data obtained. To evaluate intra- and interobserver agreement, the Intraclass Correlation Coefficient (ICC) was used. Two statistical models were used: the intraclass correlation coefficient for absolute agreement (ICC-AA) to assess absolute agreement between measurements, and the intraclass correlation coefficient for consistency (ICC-C) to estimate agreement consistency between raters and between the two assessment time points.

For intraobserver agreement (between the first and second evaluations of each evaluator), the two-way mixed effects ICC was used. For interobserver agreement (using the means of each evaluator), the two-way random effects ICC was adopted. In both situations, the interpretation of the ICC values was obtained according to Koo and Li⁽¹⁸⁾, with ICC values < 0.5 being considered of poor agreement, reasonable/moderate agreement ICC between 0.51 and 0.75, good agreement between 0.76 and 0.90, and excellent agreement ICC > 0.91. In addition to the ICC, intra- and interobserver metrics of the alpha angle and cuboid ratio were compared to each other using an unpaired t-test. All statistical analyses were performed using STATA® software (version 14.0, Stata Corporation, College Station, TX, USA), with a significance level of 5% ($p < 0.05$).



Figure 3. Ratio between the lengths of the lateral and medial walls of the cuboid.

Comparative analyses were performed to identify significant differences between patients by sex and age group. For this, the unpaired t-test (for two-by-two comparisons between the means obtained) and the Chi-square test (for comparisons between frequencies) were performed. In all analyses performed, the differences obtained were considered statistically significant when the p-value was less than 0.05 ($p < 0.05$). Statistical analyses were performed using the STATA® program (version 14.0, Stata Corporation, College Station, TX, USA).

Results

A total of 516 foot radiographs from patients treated at a private hospital in Belo Horizonte, Minas Gerais, Brazil, were analyzed. The mean patient age was 46.14 years (± 14.00), and the most prevalent characteristics were age up to 50 years and the left side, corresponding to 57.75% and 50.97%, respectively. Considering the alpha angle measurements, the mean obtained from the 516 patients was 35.62° ($\pm 4.23^\circ$), with a mean ratio of 0.52° ($\pm 0.06^\circ$) (Table 1).

The data showed that the female population had a higher mean age than the male population (49.74 versus 42.54 years, respectively) ($p = 0.000$). In the male population, the most frequent age group was younger patients (up to 50 years old: 70.93%), while in the female population, patients ≥ 51 years were the most prevalent (55.43%). The difference

Table 1. Characterization of the overall study population (n = 516)

General population (n = 516)		
Age (years)		
Mean	46.14	
± SD	14.00	
Min - Max	18 - 70	
Age group	n	%
Up to 50 years	298	57.75
≥ 51 years	218	42.25
Sex		
Female	258	50.00
Male	258	50.00
Laterality		
Right	253	49.03
Left	263	50.97
Alfa angle (°)		
Mean	35.62	
± SD	4.23	
Min - Max	21.6 - 49.2	
Ratio		
Mean	0.52	
± SD	0.06	
Min - Max	0.37 - 0.69	

SD: Standard deviation; Min: Minimum value; Max: Maximum value; n: Absolute frequency; %: Percentage.

between the percentages in each age group was significant ($p = 0.000$).

The metrics obtained in the alpha angle ($^\circ$), measured by evaluators 1 (A1) and 2 (A2) in the male and female populations show that, for males, A1 had a mean of 36.13° ($\pm 4.42^\circ$) in the first evaluation and 36.34° ($\pm 3.99^\circ$) in the second evaluation, with no statistically significant difference between the time points ($p = 0.567$), indicating good intraobserver agreement. A2 also showed similar means between the two evaluations ($36.26^\circ \pm 4.38^\circ$ and $36.03^\circ \pm 4.58^\circ$), with $p = 0.562$, reinforcing intraobserver agreement. The interobserver comparison between A1 and A2 showed no significant differences between sexes ($p > 0.05$), indicating high agreement between evaluators.

For the cuboid bone morphometric ratio, results by sex showed that, for male patients, A1 produced identical means in the two evaluations (0.52 ± 0.06 and 0.52 ± 0.05), with no statistically significant difference ($p = 0.920$), indicating high intraobserver stability. A2 also showed identical means (0.53 ± 0.05 in both evaluations), with $p = 0.467$, confirming measurement consistency. Among female patients, the mean values were 0.53 ± 0.05 in the two evaluations performed by A1 ($p = 0.688$) (Figure 3B) and identical for A2 (0.53 ± 0.05), with $p = 0.238$ (Figure 4B). The interobserver comparison between A1 and A2 showed no significant differences in either sex ($p > 0.05$), indicating high agreement between evaluators.

Table 2 presents a general comparison between female and male patients, including age, age group, laterality, and measures of the alpha angle and the ratio of the lateral to medial walls of the cuboid bone.

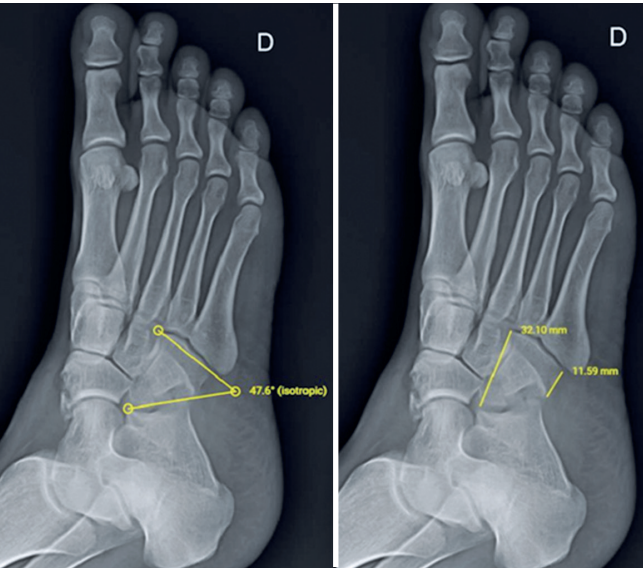


Figure 4. Radiographs with fracture-impaction of the cuboid. Alpha angle = 47.6° and cortical ratio = 0.36°.

Tables 3 and 4 show comparative analyses by age group and sex. No significant differences were observed between patients in the age groups up to 50 years and ≥ 51 years, regardless of sex, considering laterality, alpha angle, and ratio ($p > 0.05$).

Table 2. A general comparative analysis between female and male patients, considering age, age groups, laterality and measures of the alpha angle and the ratio of the lateral and medial walls of the cuboid bone

	Female (n = 258)		Male (n = 258)		p-value
Age (years)					
Mean	49.74		42.54		
$\pm$ SD	13.54		13.53		0.000 ^T
Min - Max	18 - 70		18 - 70		
Age group	n	%	n	%	
Up to 50 years	115	44.57	183	70.93	0.000 ^Q
≥ 51 years	143	55.43	75	29.07	
Laterality					
Right	118	45.74	135	52.33	0.134 ^Q
Left	140	54.26	123	47.67	
Alfa angle (°)					
Mean	35.11		36.13		
$\pm$ SD	3.97		4.42		0.006 ^T
Min - Max	21.6 - 44.4		22 - 49.2		
Ratio					
Mean	0.53		0.52		
$\pm$ SD	0.05		0.06		0.236 ^T
Min - Max	0.4 - 0.66		0.37 - 0.69		

SD: Standard deviation; Min: Minimum value; Max: Maximum value; n: Absolute frequency; %: Percentage.

*: Significant difference ($p < 0.05$); T: Unpaired t-test; Q: Chi-square test.

Table 3. Comparative analysis between female patients, considering the age group

	Female population				p-value
	Up to 50 years (n = 115)		≥ 51 years (n = 143)		
Laterality	n	%	n	%	
Right	48	41.74	70	48.95	0.248 ^Q
Left	67	58.26	73	51.05	
Alfa angle (°)					
Mean	35.05		35.17		
$\pm$ SD	4.08		3.90		0.811 ^T
Min - Max	24.5 - 44.4		21.6 - 42.0		
Ratio					
Mean	0.53		0.52		
$\pm$ SD	0.05		0.06		0.417 ^T
Min - Max	0.4 - 0.64		0.41 - 0.66		

n: Absolute frequency; %: Percentage; T: Unpaired t-test; Q: Chi-square test.

Table 5 presents the comparative analyses within each age group by sex. The alpha angle in the age group up to 50 years was the only significant variable in the comparisons

Table 4. Comparative analysis between male patients, considering the age group

	Male population				p-value
	Up to 50 years (n = 183)		≥ 51 years (n = 75)		
Laterality	n	%	n	%	
Right	95	51.91	40	53.33	0.836 ^Q
Left	88	48.09	35	46.67	
Alfa angle (°)					
Mean	36.47		35.30		
$\pm$ SD	4.43		4.31		0.052 ^T
Min - Max	23 - 48.5		22 - 49.2		
Ratio					
Mean	0.52		0.53		
$\pm$ SD	0.06		0.06		0.126 ^T
Min - Max	0.37 - 0.66		0.4 - 0.69		

n: Absolute frequency; %: Percentage; T: Unpaired t-test; Q: Chi-square test.

Table 5. Comparative analysis of the age group, considering the sex of the patients

	Age group up to 50 years				p-value
	Female (n = 115)		Male (n = 183)		
Laterality	n	%	n	%	
Right	48	41.74	95	51.91	0.087 ^Q
Left	67	58.26	88	48.09	
Alfa angle (°)					
Mean	35.05		36.47		
$\pm$ SD	4.08		4.43		0.006 ^T
Min - Max	24.5 - 44.4		23 - 48.5		
Ratio					
Mean	0.53		0.52		
$\pm$ SD	0.05		0.06		0.063 ^T
Min - Max	0.4 - 0.64		0.37 - 0.6		
	Age group ≥ 51 years				p-value
	Female (n = 143)		Male (n = 75)		
Laterality	n	%	n	%	
Right	70	48.95	40	53.33	0.539 ^Q
Left	73	51.05	35	46.67	
Alfa angle (°)					
Mean	35.17		35.30		
$\pm$ SD	3.90		4.31		0.822 ^Q
Min - Max	21.6 - 42		22 - 49.2		
Ratio					
Mean	0.52		0.53		
$\pm$ SD	0.06		0.06		0.510 ^Q
Min - Max	0.41 - 0.66		0.4 - 0.69		

n: Absolute frequency; %: Percentage.

*: Significant difference ($p < 0.05$); T: Unpaired t-test; Q: Chi-square test.

performed ($p < 0.05$). The results showed that male patients aged up to 50 years had higher means than females in the same age group (36.47° versus 35.05° , respectively) ($p = 0.006$). No significant difference was reported regarding the age group ≥ 51 years ($p > 0.05$).

Although no significant results were identified, in male patients (Table 5), the p -value for the alpha angle was borderline ($p = 0.052$), indicating a trend toward a higher mean value in male patients aged up to 50 years. These results corroborate the findings shown in Table 2, in which male patients had a higher mean alpha angle than female patients.

Discussion

This study aimed to establish two radiographic parameters to characterize the normal radiographic anatomy of the cuboid bone. The first was the angle formed between the distal and proximal articular surfaces of this bone, with its apex located lateral to the foot (alpha angle). The second radiographic parameter was the relationship between the length of the lateral and medial cortices of the cuboid. Regarding the alpha angle, male patients had a slightly higher mean angle than female patients (36.13° versus 35.11°). However, this difference has little clinical relevance due to its very small effect size. No differences were observed by laterality or ratio. No significant differences were found between patients in the age groups up to 50 years and ≥ 51 years, regardless of sex, based on injury laterality, alpha angle, and ratio.

Radiographic anatomy has long been widely studied across all areas of orthopedics, defining parameters of normality and helping professionals understand diseases and their treatments. The Böhler⁽¹⁹⁾ and Gissane⁽²⁰⁾ angles in calcaneal fracture, the metatarsophalangeal angle of the first joint in the hallux valgus, and the calcaneal inclination angle (pitch) are examples of the importance of such measurements, which assist in disease characterization, therapeutic indication, and postoperative follow-up. In addition, many other orthopedic problems are treated using angle measurements and radiographic anatomical relationships, such as distal radius fractures and patellofemoral instability.

The literature focuses on radiographic studies of the normal foot, seeking to define measures of positioning (height)⁽²¹⁾ and the relationship of the cuboid with the lateral column. Steel et al.⁽²¹⁾ measured the height of the upper point of the cuboid to the ground on lateral radiography with support to characterize the shape of the longitudinal arc. However, parameters of normality in frontal evaluation remain scarce. One of the few parameters described is the calcaneocuboid angle, which can be used to evaluate lateral column alignment, with deviations greater than 5° indicating forefoot abduction deformity⁽²²⁾. Fracture patterns with lateral joint compression (nutcracker) can lead to loss of the pyramidal shape and collapse of the lateral column, with consequent forefoot abduction and alteration of this angle.

Changes in cuboid morphology may result from articular impaction fractures involving either the distal articular surface

with the metatarsals or the calcaneal articular surface, as shown in Figure 4, altering the shape of the bone and leading to flattening of the lateral portion of the cuboid.

Deformation after crushing the cuboid may have an unfavorable course, leading to arthrosis and deformity in forefoot abduction.

Another clinical condition that can occur with changes in cuboid position and shape is Charcot's arthropathy, a disorder that often causes plantar displacement of the bone and severe hindfoot deformity (Figure 5). This condition is predisposing to plantar ulceration and osteomyelitis, and presents a higher risk of amputations and mortality⁽²³⁾.

The cuboid is a midfoot bone that contributes most to plantar/dorsal flexion⁽²⁴⁾, providing an expressive range of motion in the sagittal plane with the lateral metatarsals, an essential movement for adapting the foot to irregular surfaces. Loss of movement in the calcaneal-cuboid joint or cuboid-lateral metatarsal bones can lead to stiffness of the lateral column and translate into poor tolerance when walking on inclined or irregular surfaces⁽²⁵⁾.

In addition to its dynamic importance, the cuboid is also fundamental for the static function of the foot, as it is the main supporter of the lateral column. Shortening of the lateral column results in forefoot abduction and flatfoot, associated or not with valgus^(6,11,13,14). These biomechanical changes culminate in a mechanical dysfunction of the entire foot. To compensate for these forefoot deformities, the hindfoot (calcaneus) everts, also resulting in frontal-plane changes⁽¹³⁾.



Figure 5. Radiographs of the foot with Charcot's arthropathy.

The literature offers few studies on the radiographic anatomy of the cuboid, and even fewer provide references to define the degree of lateral impaction after fractures or to guide restoration of normality after surgical treatment. Mihalich and Early⁽²⁶⁾ recommend surgical treatment for cases of lateral column shortening, but do not define the size of this shortening. Bradshaw⁽²⁷⁾ indicates surgical treatment when lateral column shortening exceeds 2 mm. Yu et al.⁽²⁸⁾ also consider this shortening value in the surgical indication of cuboid compression fractures.

Shortening measurements in mm may be affected by technical factors, such as tube distance and foot size, which can lead to misinterpretation and inappropriate therapeutic indication.

One limitation of this study is that the values obtained were not correlated with hindfoot alignment. Therefore, it cannot be stated whether foot varus or valgus affects the shape of the cuboid. Similarly, the elevated or lowered position of the cuboid in cavus and flat feet may alter the position of the bone, leading to different angular values and wall-length measurements.

Another issue was the CI adopted. Scientific studies generally use a 95% CI. However, 90% CI is also accepted and statistically valid. The purpose of this interval was to identify a lower sample size that was within reality.

Another limitation is how the parameters were evaluated in the perioperative study. It was performed with measurements from a goniometer and a ruler, unlike the preoperative evaluation (done with computerized software), which could introduce divergence between measurements due to the lower accuracy of manual measurement. Another issue relates to the radiographic method of evaluating the parameters. Non-

weight-bearing radiographs were performed (most patients presented with traumatic injury), which could be addressed in a future study by applying analysis under weight-bearing conditions.

The alpha angle and the latero-medial cortical relationship are radiographic parameters for evaluating the lateral column and can be used intraoperatively as criteria for reducing fractures and correcting cuboidal height. In addition to studying fractures and their correction, these parameters may be useful in investigating other diseases that affect cuboid positioning, such as Charcot's arthropathy and clubfoot.

The alpha angle and the latero-medial cortical relationship are radiographic parameters for evaluating the lateral column and can be used intraoperatively as criteria for reducing fractures and correcting cuboid height. In addition to studying fractures and their correction, these parameters may be useful in investigating other diseases that affect cuboid positioning, such as Charcot's arthropathy and clubfoot.

The strength of this study was expanding methods for better anatomical analysis of the cuboid bone by creating radiographic parameters that are easy to perform and reproducible.

Conclusion

Two radiographic parameters of the cuboid bone were defined at the oblique incidence at 30°: the alpha angle, with a mean of 35.62°, and the ratio of the lateral and medial cortices of the cuboid, with a mean of 0.52°. There was no difference in the alpha angle and the ratio in relation to sex and age, except for the angle between sexes in the age group from 18 to 50 years.

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Original Article

Orthopedic management of foot deformities due to poliomyelitis sequelae

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Abstract

Objective: To evaluate the clinical and functional outcomes of surgical approaches to foot deformities due to poliomyelitis sequelae.

Methods: This observational, retrospective, descriptive study included adult patients with poliomyelitis sequelae who underwent surgical correction of foot deformities. Functional assessment was performed using the American Orthopaedic Foot and Ankle Society (AOFAS) scale, applied descriptively during postoperative follow-up. Demographic and clinical variables, type of deformity, surgical procedures, and postoperative functional scores were analyzed without formal comparisons among techniques. Postoperative follow-up ranged from 12 to 48 months (mean, 27 months), and preoperative AOFAS scores were unavailable.

Results: Ten patients were included, with a mean age of 55.3 years; most were men. Procedures included panarthrodesis, ankle arthrodesis, midtarsal arthrodesis with soft-tissue procedures, talectomy, and arthrodesis using the Ilizarov method. AOFAS scores ranged from 56 to 83 points, with a mean of 72.5. Overall postoperative functional status was satisfactory, with good results in pain, stability, and alignment, although sagittal and hindfoot mobility remained restricted, particularly after arthrodesis. The highest AOFAS score was observed after panarthrodesis, whereas the lowest scores were observed after talectomy. Three cases of superficial skin necrosis and one case of delayed union of the tibiotarsal arthrodesis were recorded; none required reoperation.

Conclusion: Surgical treatment resulted in overall satisfactory postoperative functional status in this case series. Findings should be interpreted descriptively due to the absence of preoperative AOFAS scores, small sample size, and heterogeneity of deformities and techniques. Surgical individualization was relevant, but further comparative studies with larger sample sizes are required.

Level of evidence III; Therapeutic, Retrospective Study.

Keywords: Poliomyelitis; Treatment outcome; Foot deformities; Foot; Ankle; Arthrodesis.

Introduction

Poliomyelitis is a neurotropic viral disease that predominantly affects the motor neurons of the anterior horn of the spinal cord and may result in permanent flaccid paralysis and irreversible neuromusculoskeletal sequelae⁽¹⁾. Before the widespread implementation of immunization strategies, the disease was an important cause of motor disability, with a significant impact on the function and autonomy of affected individuals. In Brazil, endemic poliovirus circulation has

been interrupted since the late 1980s through systematic vaccination programs and continuous epidemiologic surveillance, resulting in a significant reduction in new cases⁽²⁾. However, eradication did not eliminate the clinical burden of late sequelae, which persist in a residual adult population that continues to require multidisciplinary follow-up⁽³⁾.

From a functional standpoint, late poliomyelitis sequelae result from chronic neuromuscular deficits due to irreversible loss of motor units and compensatory adaptations over

Study performed at the Hospital Santa Marcelina, São Paulo, SP, Brazil.

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time, and may include manifestations consistent with post-poliomyelitis syndrome (PPS)^(1,3). This progressive neuromuscular impairment directly affects locomotor function, altering gait patterns, weight-bearing capacity, and the biomechanical efficiency of the lower limbs, with significant repercussions for functional independence and a predisposition to secondary musculoskeletal deformities⁽⁴⁾.

Among the most limiting chronic manifestations of poliomyelitis sequelae are foot deformities, particularly equinus and cavus deformities, often with varus components, resulting from an imbalance between agonist and antagonist muscle groups. These changes lead to progressive structural malalignment, loss of plantigrade support, and impaired biomechanical gait efficiency, and may progress to rigid, painful deformities that are difficult to compensate for, directly affecting stability and walking ability^(3,4).

Although currently rare, severe foot deformities related to poliomyelitis sequelae continue to be observed in specialized orthopedic practice. Previous Brazilian studies have identified poliomyelitis as an etiology in surgical series of severe foot deformities, reinforcing the clinical presence of these conditions even after disease control. Given the heterogeneity of deformities, the variable degree of joint stiffness, and differing functional demands, surgical treatment requires an individualized approach, with strategies tailored to each case. In this context, presenting a case series is particularly relevant for documenting the diversity of clinical manifestations, the therapeutic options adopted, and the functional evolution observed in clinical practice, while also enabling a systematic analysis of the functional outcomes achieved with different surgical techniques. Therefore, the objective of this study is to clinically and functionally evaluate the outcomes of the different surgical approaches used to treat foot deformities resulting from poliomyelitis sequelae by analyzing data from medical records and postoperative AOFAS scores.

Methods

This observational, retrospective, descriptive study was based on clinical and functional analysis of patients who underwent surgical treatment for foot deformities resulting from poliomyelitis sequelae and were followed at a specialized orthopedic service. Functional data were derived from AOFAS scores recorded during postoperative follow-up. The study was descriptive rather than comparative or inferential, and aimed to describe the clinical characteristics, deformities presented, surgical approaches employed, and functional outcomes recorded during postoperative follow-up. Given the condition's rarity and the heterogeneity of deformities and therapeutic strategies, cases were presented descriptively and individually, without formal comparisons among techniques.

The sample comprised adult patients with orthopedic poliomyelitis sequelae affecting the lower limbs who underwent surgery to correct foot deformities at a specialized orthopedic service. Patients with a clinical diagnosis of poliomyelitis sequelae who presented with foot deformities

associated with functional limitation and difficulty walking were included. The treating team determined surgical indication individually, and patients underwent corrective surgery provided sufficient clinical and functional data were available for analysis. Postoperative follow-up ranged from 12 to 48 months (mean, 27 months). Patients with incomplete electronic medical records, no postoperative functional records, or foot deformities attributed to other neuromuscular etiologies other than poliomyelitis were excluded. The study was conducted in accordance with current ethical principles, after approval by the Institutional Review Board.

Once the study population was defined, the indication for surgical treatment was determined individually based on each patient's clinical evaluation, considering the type of foot deformity, the degree of joint stiffness, the pattern of muscle imbalance, and the functional demands identified at the time of treatment decision-making. Treatment decisions were made by the assisting team as part of routine clinical practice. The techniques employed included soft-tissue procedures, corrective osteotomies, and isolated or combined arthrodeses, depending on the specific characteristics of each deformity. In cases of rigid deformity or significant joint instability, joint stabilization procedures were selected to achieve a stable, plantigrade foot for weight bearing during gait, even at the expense of joint mobility. Considering the heterogeneity of deformities and surgical approaches, no formal comparisons were performed among techniques; the main objective was to correct alignment and improve functional stability.

To document the functional effects of the approaches used, functional performance was assessed using the AOFAS scale, which is used exclusively as a descriptive instrument and assesses domains related to pain, function, and foot and ankle alignment. Postoperative scores were used to describe functional status throughout the clinical follow-up, without comparative or inferential analyses among surgical techniques. The AOFAS scale is not an instrument specifically validated for patients with neuromuscular diseases; therefore, its results should be interpreted cautiously and only within the descriptive context of the present case series. No preoperative AOFAS scores were available in the retrospective records, making preoperative-to-postoperative comparisons impossible. The available records did not allow standardization of the exact timing of the AOFAS evaluation relative to surgery; therefore, the scores were treated only as descriptive measures during postoperative follow-up.

Clinical and functional data from these evaluations were organized and stored in Microsoft Excel® spreadsheets for tabulation and analysis. The variables analyzed included age, sex, date of infection, operated side, and previous physical activity, obtained from clinical records in the electronic medical records; participants were identified by sequential numbers, and no names were collected. Table 1 presents the sample characteristics, including clinical and demographic data for the ten included patients. For age, minimum, maximum, mean, and standard deviation values were calculated. For the AOFAS score, the mean, median,

Table 1. Characterization of the analyzed sample

Patient ID	Age	Sex	Profession	Side	Procedure	AOFAS
1	60	M	Retired	Right	Panarthrodesis	68
2	55	M	Store clerk	Right	Panarthrodesis	73
3	50	M	Office clerk	Right	Midtarsal arthrodesis + soft-tissue procedures	80
4	59	M	Carpenter	Left	Ankle arthrodesis	77
5	57	M	Retired	Right	Talectomy	66
6	49	M	Salesperson	Left	Arthrodesis + Ilizarov	66
7	51	M	Fare collector	Right	Panarthrodesis	76
8	61	F	Housekeeper	Left	Talectomy	56
9	55	F	Housekeeper	Right	Panarthrodesis	83
10	56	M	Construction worker	Left	Ankle arthrodesis	80

AOFAS: American Orthopaedic Foot and Ankle Society.

and standard deviation values were calculated. To explore the association between age and AOFAS score, Pearson and Spearman correlation coefficients were applied, according to the data distribution.

In addition, frequency analysis was performed for each AOFAS item, considering the pain, function, and alignment domains; the results are shown in Table 2.

Results

The results present a clinical and functional analysis of ten patients who underwent surgery to correct foot deformities resulting from poliomyelitis sequelae, based on medical records and the AOFAS scores recorded during postoperative follow-up. Demographic and clinical characteristics and the surgical procedures performed are detailed in Table 1.

Patient age ranged from 49 to 61 years, with a mean of 55.3 years (± 3.98). Eight patients were men and two were women. Regarding the affected side, six patients presented paralysis in the right limb and four in the left limb. Regarding surgical procedures, four patients underwent panarthrodesis (Figure 1), two underwent ankle arthrodesis, two underwent talectomies, one underwent midtarsal arthrodesis with associated soft-tissue procedures, and one underwent arthrodesis using the Ilizarov method.

Individual AOFAS scores, presented in Table 1, ranged from 56 to 83 points. The mean score was 72.5 points (SD = 7.95), and the median was 74.5.

To explore the association between age and AOFAS score, Pearson and Spearman correlation coefficients were applied. Both tests showed a weak correlation, with Pearson's coefficient of -0.38 and Spearman's coefficient of -0.33, indicating no strong association between age and functional performance. The results are shown in the scatter plot in Figure 2.

Table 2 presents the distribution of AOFAS scores across pain, function, and alignment domains, providing an overview of the sample's functional performance.

Table 3 presents the individual scores across AOFAS domains for each patient, distinguishing the pain, function, and foot and ankle alignment components.

The following description refers exclusively to score distributions across the AOFAS domains. In the pain domain, six patients had a maximum score (40 points), and four had a score corresponding to mild pain (30 points). Regarding functional items, most patients had restricted limitations in recreational activities, did not require gait support, and had no limitations in activities of daily living, whereas three patients achieved the maximum score for this item. In the gait subdomain, scores varied among no or slight abnormality, evident abnormality, and marked abnormality. All patients had the maximum score in the ankle and hindfoot stability domain. In contrast, all had zero scores in the sagittal and hindfoot mobility domains. For hindfoot alignment, eight patients had the maximum score, one had an intermediate score, and one had a zero score.

Regarding postoperative complications, three patients developed superficial skin necrosis that resolved satisfactorily. One patient had delayed union of the tibiotalar arthrodesis, which progressed without additional complications. No patient required reoperation.

Overall, these findings summarize the distribution of AOFAS scores in the analyzed sample and characterize the functional profile observed in patients with foot deformities resulting from poliomyelitis sequelae, a condition that is currently rare in Brazil. Presenting these results as a case series allows objective documentation of the functional variability associated with different deformities and the surgical approaches used during postoperative follow-up.

Discussion

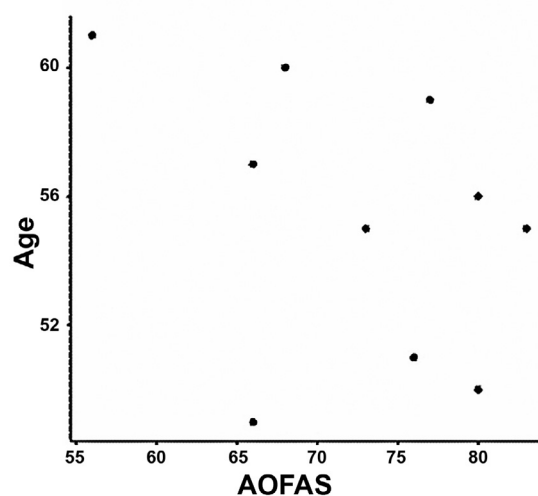
The findings of the present study should be interpreted considering the current rarity of poliomyelitis in Brazil and the consequent scarcity of contemporary series that systematically address surgical strategies to correct residual

Table 2. AOFAS score frequency distribution

AOFAS (up to 100 points) Answer (Score)	Frequency	Frequency (%)
Pain (up to 40 points)		
None (40)	6	60%
Mild (30)	4	40%
Moderate (20)	-	-
Severe (0)	-	-
FUNCTIONAL (up to 50 points)		
Activity limitations, need for support		
No limitation, no support (10)	3	30%
No limitation in daily activities or recreational activities, no support (7)	7	70%
Limitation in daily activities (4)	-	-
Severe limitation in daily activities (0)	-	-
Maximum walking distance (blocks)		
More than 6 (5)	3	30%
From 4 to 6 (4)	7	70%
From 1 to 3 (2)	-	-
Less than 1 (0)	-	-
Walking surfaces		
No difficulty (5)	-	-
Some difficulty (3)	10	100%
Severe difficulty (0)	-	-
Gait abnormality		
None (8)	3	30%
Evident (4)	6	60%
Marked (0)	1	10%
Sagittal mobility (flexion + extension)		
Normal ($\geq 30^\circ$) (8)	-	-
Moderate (15° - 29°) (4)	-	-
Severe ($< 15^\circ$) (0)	10	100%
Hindfoot mobility (inversion + eversion)		
Normal (75-100%) (6)	-	-
Moderate (25-74%) (3)	-	-
Severe ($< 25\%$) (0)	10	100%
Ankle and hindfoot stability		
Stable (8)	10	100%
Unstable (0)	-	-
Alignment (up to 10 points)		
Good (10)	8	80%
Fair (5)	1	10%
Poor (0)	1	10%

AOFAS: American Orthopaedic Foot and Ankle Society.

foot deformities in this population. Although eradicated from an epidemiologic perspective, poliomyelitis remains clinically relevant due to late neuromuscular sequelae, often associated with muscle imbalance, progressive joint stiffness, and complex foot and ankle deformities, requiring individualized

**Figure 1.** Postoperative radiography panarthrodesis.**Figure 2.** Scatter plot of age versus AOFAS score.

therapeutic approaches based on the deforming pattern and degree of functional impairment⁽¹⁻⁵⁾. Since the classic descriptions by Seddon et al.⁽⁶⁾, it has been established that the primary objective of orthopedic treatment of poliomyelitis is to obtain a stable and functional plantigrade foot, even if this requires sacrificing joint mobility, a principle that remains valid in current clinical practice⁽⁶⁾. In this context, case series remain clinically and scientifically relevant, especially given the disease's low prevalence and the limitations of conducting large-sample studies in this population⁽²⁻⁵⁾.

In the analyzed sample, the mean AOFAS score was 72.5 points, with wide individual variation (56 to 83 points), reflecting clinical heterogeneity among patients and the surgical strategies employed. Among the procedures performed, the highest individual AOFAS score was observed in a patient who underwent panarthrodesis (83 points). This finding should be interpreted descriptively, since the retrospective design, small sample size, and heterogeneity of deformities and techniques do not allow establishing superiority or a causal relationship between panarthrodesis and functional performance. The therapeutic rationale

Table 3. AOFAS score breakdown

ID	PAIN		FUNCTIONAL						ALIGNMENT
	Pain	Limitation	Distance	Surfaces	Gait	Sagittal mobility	Hindfoot mobility	Stabilities	Alignment
1	None (40)	Limitation in recreational activities (7)	More than 6 (5)	Some difficulty (3)	Marked (0)	Severe restriction (0)	Severe restriction (0)	Stable (8)	Fair (5)
2	Mild (30)	No limitation, no support (10)	4 to 6 (4)	Some difficulty (3)	None, mild (8)	Severe restriction (0)	Severe restriction (0)	Stable (8)	Good (10)
3	None (40)	No limitation, no support (10)	More than 6 (5)	Some difficulty (3)	Evident (4)	Severe restriction (0)	Severe restriction (0)	Stable (8)	Good (10)
4	None (40)	Limitation in recreational activities (7)	More than 6 (5)	Some difficulty (3)	Evident (4)	Severe restriction (0)	Severe restriction (0)	Stable (8)	Good (10)
5	Mild (30)	Limitation in recreational activities (7)	4 to 6 (4)	Some difficulty (3)	Evident (4)	Severe restriction (0)	Severe restriction (0)	Stable (8)	Good (10)
6	Mild (30)	Limitation in recreational activities (7)	4 to 6 (4)	Some difficulty (3)	Evident (4)	Severe restriction (0)	Severe restriction (0)	Stable (8)	Good (10)
7	None (40)	Limitation in recreational activities (7)	4 to 6 (4)	Some difficulty (3)	Evident (4)	Severe restriction (0)	Severe restriction (0)	Stable (8)	Good (10)
8	Mild (30)	Limitation in recreational activities (7)	4 to 6 (4)	Some difficulty (3)	Evident (4)	Severe restriction (0)	Severe restriction (0)	Stable (8)	Poor (0)
9	None (40)	No limitation, no support (10)	4 to 6 (4)	Some difficulty (3)	None, mild (8)	Severe restriction (0)	Severe restriction (0)	Stable (8)	Good (10)
10	None (40)	Limitation in recreational activities (7)	4 to 6 (4)	Some difficulty (3)	None, mild (8)	Severe restriction (0)	Severe restriction (0)	Stable (8)	Good (10)

AOFAS: American Orthopaedic Foot and Ankle Society.

aligns with the classical principles of treating paralytic sequelae described by Seddon et al.⁽⁶⁾ and is supported by contemporary series that evaluate the surgical management of rigid echinocavovarus deformities associated with poliomyelitis⁽⁷⁻⁹⁾.

The functional scores are within the range reported in the literature for rigid neuromuscular deformities undergoing reconstructive surgical treatment. However, interpreting the AOFAS total score in isolation is limited; a segmented analysis of its domains is more informative. This approach identifies a characteristic pattern after multiple hindfoot and midfoot arthrodeses: pain relief and increased structural stability at the expense of significantly reduced joint mobility. From a biomechanical perspective, joint fusion reduces the degrees of freedom of the ankle and hindfoot, with a direct impact on gait kinematics, particularly on the ability to adapt to irregular surfaces and on the efficiency of the gait cycle, as demonstrated in classic and functional gait analysis studies^(8,9). These results reinforce that the stability achieved is sufficient for weight bearing and functional gait, the central objective of treating poliomyelitis sequelae, in line with principles widely adopted in rehabilitation programs for this population⁽⁵⁾.

In contrast, all patients showed marked restriction of sagittal and hindfoot mobility, reflected by zero scores in these

domains of the AOFAS scale. This finding is expected after procedures involving multiple arthrodeses and aligns with contemporary studies evaluating reconstructive strategies in neurological deformities, where loss of range of motion is recognized as an inherent consequence of joint fusion⁽¹⁰⁾. From a functional perspective, this limitation can affect gait adaptation to irregular surfaces and fine adjustments during the gait cycle, phenomena classically described in the literature on human gait analysis⁽⁸⁾ and corroborated by studies in patients with post-poliomyelitis syndrome undergoing functional walking tests⁽⁹⁾.

The worst functional outcomes were observed in the patient undergoing talectomy, who had the lowest AOFAS total score and zero score in the alignment domain. The literature describes talectomy as an exceptional procedure, reserved for extremely rigid and complex deformities, often associated with residual biomechanical ankle and hindfoot impairment and more limited functional outcomes⁽¹¹⁾. These findings are reinforced by case reports demonstrating difficulties maintaining alignment and functional recovery after this type of intervention⁽¹²⁾.

The patient who underwent arthrodesis using the Ilizarov method achieved an intermediate functional result, consistent with the literature describing the method as an effective alternative for gradual correction of rigid and complex

deformities related to poliomyelitis. The biomechanical rationale for gradual controlled tension correction was originally described by Ilizarov, remaining as the conceptual basis of the method and supporting its clinical application in complex foot and ankle deformities. Modern clinical series confirm the effectiveness of this approach, although they highlight longer treatment times and the need for strict follow-up^(10,13).

The exploratory analysis of the correlation between age and AOFAS score showed only a weak association, suggesting that in this sample, chronological age alone was not a determinant of postoperative functional performance. This finding reinforces the notion that factors such as deformity pattern, the degree of joint stiffness, neuromuscular involvement, and the surgical strategy adopted have a more relevant influence on functional outcomes than chronological age alone.

Finally, the results should be interpreted with caution, considering the small sample size, the heterogeneity of deformities and surgical techniques employed, as well as the retrospective and descriptive design of this case series. The absence of preoperative AOFAS scores prevents the evaluation of functional change between the preoperative and postoperative periods. Nevertheless, the study contributes

to the literature by integrating epidemiologic background, classical principles as described by Seddon et al.⁽⁶⁾, and contemporary clinical evidence, providing an updated view of the surgical management of orthopedic poliomyelitis sequelae.

Conclusion

The clinical and functional analysis, based on the AOFAS scores, suggests overall satisfactory postoperative functional status after surgical interventions performed to correct foot deformities resulting from poliomyelitis sequelae in this case series. The highest individual AOFAS score was observed in a patient who underwent panarthrodesis (83 points), whereas the lowest scores were observed in patients who underwent talectomy; these findings should be interpreted descriptively and do not allow conclusions regarding superiority or causal relationships among techniques. Despite the loss of mobility inherent in arthrodesis, functional performance was maintained, possibly due to increased stability and adequate pain control. Overall, this series suggests that well-indicated surgical interventions may improve stability and function, a finding that requires confirmation in studies with larger sample sizes and comparative designs.

Authors' contributions: Each author contributed individually and significantly to the development of this article: SDSP *(<https://orcid.org/0000-0001-5957-527X>) Conceived and planned the activities that led to the study, participated in the review process, performed the surgeries, data collection, approved the final version; JMM *(<https://orcid.org/0000-0001-6039-4599>) Interpreted the results of the study and participated in the review process; MAGR *(<https://orcid.org/0000-0002-7424-9074>) Performed the surgeries and data collection; IAR *(<https://orcid.org/0009-0005-1228-3057>) Interpreted the results of the study, participated in the review process, bibliographic review, and formatting of the article; MEBS *(<https://orcid.org/0009-0006-1560-7923>) Interpreted the results of the study, participated in the review process, bibliographic review, and formatting of the article. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) .

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Original Article

Postoperative evaluation of patients undergoing minimally invasive treatment for acute Achilles tendon rupture

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Abstract

Objective: To evaluate the clinical and functional outcomes of patients undergoing percutaneous repair of acute Achilles tendon rupture with the Tenolig® device, associated with a structured rehabilitation protocol with eccentric exercises adapted from Alfredson's principles.

Methods: Observational, retrospective, and descriptive study with 20 patients treated with rupture less than five days. Cases with clinical and ultrasound diagnosis and distal stump suitable for the device were included. Insertional injuries, re-rupture, previous surgeries in the affected limb, and comorbidities with potential functional or scarring impairment were excluded. The postoperative protocol included initial immobilization in plantar flexion, weight-bearing progression, protected physiotherapy, and eccentric exercises after week 12. The functional evaluation used the Achilles Tendon Total Rupture Score (ATRS) and timed monopodal exercise. The median follow-up was 24 ± 4.6 months.

Results: The sample included 20 patients, with a mean age of 39.7 ± 13.2 years. The mean ATRS was 98.1 ± 3.4 points, with a median of 100 and a range of 86-100. The mean monopodal exercise time was 31.8 seconds. There was a re-rupture (5%) without infection, scarring complications, or sural nerve paresthesia.

Conclusion: Minimally invasive repair with Tenolig®, combined with structured rehabilitation, showed favorable outcomes and a low complication rate in this case series. The interpretation is limited due to the small sample size, retrospective design, and absence of a comparison group.

Level of Evidence IV; Descriptive Observational Study.

Keywords: Achilles tendon; Rupture; Minimally invasive surgery; Rehabilitation; Eccentric exercise.

Introduction

Acute Achilles tendon rupture is one of the most frequent injuries to the lower limb⁽¹⁾, mainly affecting physically active individuals of productive age⁽²⁾. Despite advances in surgical and rehabilitative treatment, controversies remain about the best therapeutic approach, especially balancing early functional recovery with reduced postoperative complications⁽³⁾.

In recent decades, minimally invasive techniques have gained prominence for reducing trauma to soft tissues, lowering rates of surgical wound-related complications, and enabling earlier mobilization compared with conventional open techniques⁽⁴⁾. Among these techniques, the Tenolig® device has been described as a promising alternative for percutaneous stabilization of tendon stumps, enabling adequate functional healing and accelerated rehabilitation⁽⁵⁾.

Study performed at the Departamento de Ortopedia e Traumatologia, Hospital Santa Marcelina, São Paulo, SP, Brazil.

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However, despite the increasing use of percutaneous techniques, the literature still has limitations in standardizing rehabilitation protocols, evaluating postoperative function, and analyzing complications associated with Tenolig®. In addition, few national studies describe the clinical and functional outcomes of this technique when combined with the eccentric execution protocol of Alfredson et al.⁽⁶⁾, especially in populations with varying levels of adherence to physiotherapeutic treatment.

Thus, the objective of this study is to evaluate the clinical and functional outcomes, complications, and degree of functional recovery in patients undergoing minimally invasive treatment of acute Achilles tendon rupture using the Tenolig® device, along with a structured rehabilitation protocol with eccentric exercises adapted from the principles described by Alfredson et al.⁽⁶⁾.

Methods

This retrospective, descriptive observational study was conducted in accordance with Resolution No. 466/12 of the National Health Council and approved by the Institutional Review Board.

Patients with acute Achilles tendon rupture were included if the time from injury was less than five days, the diagnosis was confirmed by clinical and ultrasound assessment, and the tendon stumps could be identified to assess suitability for the percutaneous technique. All patients underwent minimally invasive surgical treatment using the Tenolig® device. Exclusion criteria included cases of previous re-rupture, previous surgery on the affected limb, insertional Achilles tendon injuries, and comorbidities potentially associated with worse functional or scar evolution, including decompensated diabetes mellitus, decompensated or clinically significant peripheral vasculopathies, neuropathies, rheumatologic diseases, chronic renal failure, active infection, and chronic use of corticosteroids.

All patients who fully met the inclusion criteria during the analysis period were included, resulting in a final sample of 20 participants. All underwent the same postoperative protocol, structured in progressive phases based on the clinical evolution observed during outpatient follow-up.

In the first two weeks, they remained non-weight-bearing, using crutches and ankle immobilization in plantar flexion. Between the second and sixth weeks, an orthosis with wedges was used, and progressive partial weight-bearing and protected physical therapy were initiated, including active mobility up to the neutral position and isometric exercises. In the sixth and eighth weeks, the wedges were progressively removed, with increased weight-bearing, gait training, and isometric and concentric strengthening. Between the eighth and tenth weeks, the orthosis was gradually removed as mobility, strength, balance, and proprioception improved. After the tenth week, eccentric exercises adapted from the principles of Alfredson et al.⁽⁶⁾ were introduced, and patients returned to physical activities progressively and individually, according to clinical and functional progress.

The Tenolig® device was not routinely removed postoperatively. All patients were properly oriented to the proposed surgical procedures and postoperative follow-up, both during hospitalization and at subsequent outpatient follow-up.

All surgical procedures and initial postoperative follow-up were completed before including patients in the study. After Institutional Review Board approval, eligible participants were invited to participate during outpatient follow-up. The Informed Consent Form (ICF) was presented, read, and discussed individually, with all questions clarified before signing. Consent was obtained before the application of the Achilles Tendon Total Rupture Score (ATRS) questionnaire and the performance of the functional exercise. Medical assistance was fully ensured during all stages of treatment. The data on the surgical procedure and the postoperative progress were obtained retrospectively by reviewing medical records, while preserving the identity and confidentiality of the participants.

The variables analyzed included age, sex, affected side, body mass index, smoking, and physical activity, which were organized in an electronic spreadsheet in Microsoft Excel 2016.

This technique is based on established anatomical principles and is widely used in foot and ankle surgery. The following describes the step-by-step surgical technique used: the patient is in a prone position under spinal anesthesia. Then, asepsis and antisepsis of the affected lower limb are performed. Sterile fields are positioned, and a sterile pad is placed in the anterior region of the ankle to initially maintain it at 90°. The surgical preparation materials are organized: the Tenolig kit, consisting of polyester suture wire, needles, harpoons, and washers (Figure 1).

The proximal and distal stumps of the ruptured tendon are marked by simple palpation (Figure 2).

The proximal entry points, located 5 cm above the injured region, were defined on the posteromedial and posterolateral surfaces of the tendon, as well as the distal exit points, 5 cm below the injury, also on the posteromedial and posterolateral surfaces (Figure 3).

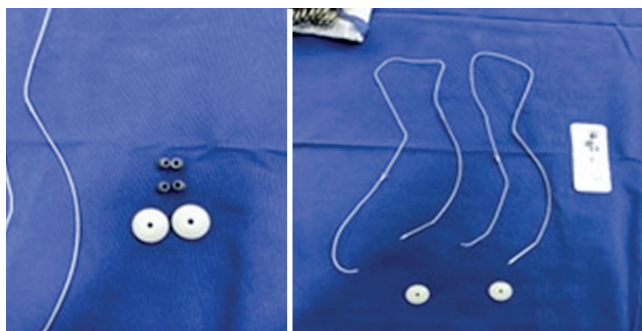


Figure 1. Materials used in the technique with Tenolig®.

The surgeon makes a small incision at the entry point and inserts the first Tenolig® using forceps. The needle penetrates the tendon perpendicularly, and the surgeon notices its path crossing the space beneath the finger (Figure 4). The needle then passes through the distal stump and emerges at the previously marked exit point. The surgeon then pulls the needle until the anchor is positioned at the level of the proximal entry point (Figure 5).



Figure 2. Identification of injured tendon stumps.



Figure 3. Small incision at entry site viewing proximal Achilles tendon stump.



Figure 4. Technique of passage of Tenolig® devices.

The second Tenolig® is inserted in the same way, on the opposite side. To tension the implant, remove the pad and position the ankle in maximal plantar flexion. Tighten both wires simultaneously to ensure the anchors are properly secured. The plastic discs are threaded with the convex surface facing the skin, and washers are secured using a crimping instrument. The implant is tested after tension relaxation of the wires.

The distal ends of the threads are cut 3 cm from the washers, and proximal sutures are performed. A molded compress is positioned under the discs, followed by sterile dressing. At the end of the procedure, a cast boot is applied to keep the ankle in plantar flexion.

The same team specialized in foot and ankle surgery performed the procedures and postoperative follow-up to standardize technique, minimize treatment-related variables, and ensure greater uniformity in clinical and functional patient evaluation.

Figure 6 illustrates the postoperative period for one patient in the study. During the clinical evaluation, Thompson's test was performed, revealing that compression of the triceps surae muscles elicited plantar flexion of the foot. This finding demonstrates the adequate coaptation of the tendon stumps and suggests the restoration of the anatomical and functional continuity of the Achilles tendon (Figure 7).

Figures 8 and 9 show active heel-lift exercises at two months postoperatively, performed with bipodal and monopodal support, without passive stretching or forced dorsiflexion. The images were used solely to illustrate the functional progression observed during outpatient follow-up and were not used as an objective method to evaluate muscle strength. Until the tenth week, rehabilitation was based on protected mobility, gait training, and isometric and concentric strengthening; eccentric exercises were adapted from Alfredson et al.⁽⁶⁾ and were introduced later. Because the evaluation was qualitative and lacked dynamometry or standardized functional tests, it was not possible to measure residual deficits in the strength or resistance of the gastrocnemius-soleus complex.



Figure 5. Wire passages and insertion in the proximal and distal tendon stumps.



Figure 6. Immediate operative image, in which the patient was placed in prone position, with ankles out of the stretcher, with knees in 90° flexion. Slight plantar flexion of the ankle was observed.



Figure 8. Patient after two months of surgical treatment, performing bilateral elevation of the heels during the functional progression of rehabilitation. The image is illustrative and does not represent a passive stretching exercise or an objective method for evaluating muscle strength.



Figure 7. Thompson's test performed in the immediate postoperative period, showing plantar flexion of the ankle after compression of the triceps surae, a result compatible with the restoration of anatomical continuity and functional integrity of the Achilles tendon.



Figure 9. Patient two months after surgical treatment, performing monopodal support with heel elevation during supervised outpatient evaluation. The execution of the movement was recorded qualitatively, without objective measurement of strength, elevation height, or muscle work.

The findings suggest adequate healing and restoration of Achilles tendon integrity, with satisfactory recovery of gastrocnemius-soleus complex function.

Functional assessment was performed using the ATRS, a specific instrument for patients with Achilles tendon rupture⁽⁷⁾. The questionnaire consists of ten items, each scored from 0 to 10, with 0 indicating the greatest limitation and 10 the absence of limitation. The sum of the ten items yields a total score of 0 to 100 points, with higher values indicating better function. The mean, standard deviation, median, and minimum and maximum values of the total ATRS were calculated.

The protocol of Alfredson et al.⁽⁶⁾, adapted to the postoperative context, was incorporated into the strengthening phase of rehabilitation because it is clinically applicable, reproducible, and well understood by patients, especially those who have greater difficulty adhering to more complex physiotherapeutic programs. Its use was based on the possibility of persistent residual pain and tendinopathic symptoms after open surgical repair of the Achilles tendon. Thus, progressive eccentric weight-bearing exercises were used in patients undergoing minimally invasive repair, and tolerance to monopodal exercise was evaluated during outpatient follow-up to guide individualized rehabilitation progression. The timed monopodal exercise served as a complementary clinical evaluation of the gastrocnemius-soleus complex's tolerance to weight-bearing and is not a validated test for objectively measuring muscle strength or diagnosing tendinopathy.

All questionnaires and functional assessments were applied during outpatient follow-up by the team responsible for postoperative follow-up of patients.

No postoperative complications related to healing, superficial infection, surgical wound dehiscence, or sural nerve paresthesias were observed during follow-up.

Results

Table 1 shows the sociodemographic and clinical profile of the 20 patients included in the study.

Twenty patients undergoing minimally invasive treatment of acute Achilles tendon rupture with the Tenolig® device were evaluated. The sample consisted of 15 men (75%) and five women (25%), with a mean age of 39.7 ± 13.2 years. The right side was the most affected, corresponding to the majority of the cases evaluated.

The mean body mass index was 27.3 ± 3.3 kg/m², ranging between 22.3 and 33.3 kg/m². Four patients (20%) reported active smoking, and eight patient reports regular physical activity (40%).

The mean postoperative follow-up was 24 ± 4.6 months, performed on an outpatient basis by the same team responsible for the surgical procedure and physiotherapeutic follow-up.

Table 2 shows the results by each ATRS domain. Each item is scored on a scale from 0 to 10, in which 0 corresponds to the greatest limitation and 10 to the absence of limitation. The sum of the ten items yields a total score of 0 to 100 points, with higher values indicating better function.

Table 3 shows the descriptive measures of the total ATRS score. The mean score was 98.1 ± 3.4 points, with a median of 100 points and a range of 86 to 100 points. Eleven patients (55%) reached the maximum score of 100 points.

Table 1. Sociodemographic and clinical characteristics of the patients included in the study

Patient	Sex	Age	Side	BMI	Smoking	Physical activity	Injury date
1 ^o	M	24	D	27.7	Yes	Yes	08/28/2021
2 ^o	M	26	D	23.5	No	No	01/23/2019
3 ^o	M	27	D	26.9	No	No	04/03/2020
4 ^o	M	28	D	24.8	No	No	09/11/2021
5 ^o	M	28	D	25.2	No	Yes	10/03/2018
6 ^o	M	29	D	27.4	No	Yes	05/01/2021
7 ^o	M	31	D	25.1	No	No	03/20/2018
8 ^o	M	33	D	30.2	Yes	No	04/22/2021
9 ^o	F	35	D	22.3	No	No	10/06/2020
10 ^o	M	37	D	31.4	No	No	11/13/2019
11 ^o	F	39	D	30.4	No	Yes	07/27/2021
12 ^o	M	40	D	29.8	No	Yes	07/25/2020
13 ^o	F	42	D	26.7	No	Yes	04/02/2018
14 ^o	F	43	E	30.6	No	Yes	01/30/2021
15 ^o	M	46	E	32.4	Yes	No	06/19/2020
16 ^o	M	48	D	26.3	No	No	05/21/2021
17 ^o	F	55	E	33.3	No	No	09/25/2020
18 ^o	M	57	D	23.7	Yes	Yes	05/26/2018
19 ^o	M	63	D	23.6	No	No	05/08/2018
20 ^o	M	64	D	25.3	No	No	09/18/2018

BMI: Body mass index.

In the pain and heavy physical activity domains, all participants scored 10 points, indicating no limitation. For the item on decreased calf and Achilles tendon strength, 15 patients (75%) had the maximum score, while five (25%) showed some intermediate limitation. In the other domains, 18 patients (90%) obtained the maximum score.

Overall, the results showed low overall functional limitation. Residual limitations were observed mainly in strength, muscle fatigue, stiffness, activities of daily living, and sports activities with greater functional demands. Thus, patients who underwent minimally invasive treatment had high functional scores on the ATRS evaluation.

According to Table 4, the mean time to perform the exercise was half a minute, with no pain component during the movement.

In the complementary functional evaluation, based on an adaptation of the principles of the protocol of Alfredson et al.⁽⁶⁾, each patient performed a monopodal heel lift exercise with an eccentric phase of controlled descent, maintaining the position for the longest time tolerated. The maintenance time was individually timed, with a mean of 31.8 seconds. No relevant pain complaints were reported during the evaluation, and all patients completed the proposed exercise.

Table 2. Result of the application of the Achilles tendon total rupture score questionnaire

Item	N*	Ten (without limitation)	Zero (with limitation)	Other measurements (1-9 points)
Are you limited because of decreased strength in the calf/Achilles tendon?	20	15	0	5
Are you limited because of fatigue in the calf/Achilles tendon?	20	18	0	2
Are you limited because of stiffness in the calf/Achilles tendon?	20	18	0	2
Are you limited because of pain in the calf/Achilles tendon?	20	20	0	0
Are you limited during activities of daily living?	20	18	0	2
Are you limited when walking on uneven surfaces?	20	18	0	2
Are you limited when walking quickly uphill or on a slope?	20	18	0	2
Are you limited during activities that include running?	20	18	0	2
Are you limited during activities that include jumping?	20	18	0	2
Are you limited when performing heavy physical work?	20	20	0	0

Table 3. Achilles tendon total rupture score at final assessment

ATRS domain	Mean $\pm$ SD	Median	Minimum-maximum	Maximum score, n (%)
Diminuição da força	9.5 $\pm$ 1.1	10	7-10	15 (75%)
Fadiga	9.9 $\pm$ 0.5	10	8-10	18 (90%)
Rigidez	9.8 $\pm$ 0.8	10	7-10	18 (90%)
Dor	10.0 $\pm$ 0.0	10	10-10	20 (100%)
Atividades da vida diária	9.7 $\pm$ 1.0	10	6-10	18 (90%)
Caminhada em superfícies irregulares	9.9 $\pm$ 0.5	10	8-10	18 (90%)
Caminhada rápida em subida ou ladeira	9.8 $\pm$ 0.6	10	8-10	18 (90%)
Atividades que incluem corrida	9.8 $\pm$ 0.6	10	8-10	18 (90%)
Atividades que incluem saltos	9.9 $\pm$ 0.5	10	8-10	18 (90%)
Trabalho físico pesado	10.0 $\pm$ 0.0	10	10-10	20 (100%)
ATRS total	98.1 $\pm$ 3.4	100	86-100	11 (55%)

Note: Each ATRS item ranges from 0 to 10, with 0 corresponding to the greatest limitation and 10 to the absence of limitation. The sum of the ten items yields a total score of 0 to 100 points, with higher values indicating better function. In the last column, the maximum score corresponds to 10 points in each domain and 100 points in the total ATRS.

Abbreviations: ATRS: Achilles Tendon Total Rupture Score; SD: Standard deviation.

Table 4. Results of the timed monopodal functional assessment, based on the principles of Alfredson et al.⁽⁶⁾

N = Total	Exercise total time	Mean time per patient
20	637 segundos	31.85 segundos

A case of re-rupture (5%) was observed approximately two months after the initial procedure, with significant functional limitation at follow-up. No postoperative complications related to healing, superficial infection, surgical wound dehiscence, or sural nerve paresthesias were observed during follow-up.

One patient had previously been diagnosed with peripheral obstructive arterial disease, clinically controlled and monitored by a specialist. Because the patient did not have decompensated vasculopathy or documented scarring, the patient did not meet the exclusion criteria and was retained in the analysis. However, during follow-up, the patient presented limitations in fully completing the physiotherapeutic protocol.

There was greater difficulty in adhering to the rehabilitation protocol in patients with less socio-educational support, especially in relation to the understanding and regularity of home exercises.

Discussion

This study evaluated the clinical and functional outcomes of patients undergoing minimally invasive treatment of acute Achilles tendon rupture with the Tenolig® device, along with a rehabilitation protocol based on the principles described by Alfredson et al.⁽⁶⁾. The main findings were favorable functional outcomes on the ATRS score, a low re-rupture rate, and no neurological or healing-related complications during the mean follow-up of two years.

The small sample size is a limitation of this study. The final sample consisted of 20 patients, and the small number of participants was related to the unicentric nature of the research, the selective use of the Tenolig® device in a highly complex hospital institution, the limited number of cases that fully met the eligibility criteria, and the availability of patients to participate and perform functional evaluations. No sample selection was performed, and all eligible patients were included during the analysis period.

The epidemiological profile of the patients evaluated was similar to that described in the literature, with a predominance of physically active males of productive age. Previous epidemiological studies have shown a progressive increase in the incidence of Achilles tendon ruptures, especially among recreational sports practitioners⁽⁸⁾.

In recent decades, minimally invasive techniques have become a prominent option in the surgical treatment of acute Achilles tendon rupture. Comparative studies show that these approaches cause less soft-tissue trauma and have lower rates of surgical-wound complications, such as infection, skin necrosis, dehiscence, and scar adhesions, than conventional open techniques⁽⁹⁾. Consistent with these findings, no complications related to healing, superficial infection, or skin injury were observed in patients in this series.

Among the percutaneous techniques described for treating this injury, including Ma and Griffith, Dresden, PARS, and Achillon, the Tenolig® device offers features that favor clinical use, such as shorter tissue dissection, shorter surgical time,

and the potential for early functional mobilization. Although implant cost and the need for technical familiarity may limit its use in some services, specific studies on the Tenolig® device support its use as a minimally invasive alternative for treating acute Achilles tendon ruptures⁽⁵⁾. Less invasive techniques have also been described in other clinical contexts, including treatment of chronic Achilles tendon ruptures⁽¹⁰⁾.

The observed re-rupture rate was 5%. In a comparative study of patients with acute complete Achilles tendon rupture, Cretnik et al.⁽¹¹⁾ reported re-rupture rates of 3.7% after percutaneous repair and 2.8% after open repair, with no statistically significant difference between techniques. Although the reduced sample size limits direct comparisons, the observed result was close to that reported for percutaneous treatment of acute ruptures.

Despite its low incidence, re-rupture remains one of the most relevant complications of this injury, which can significantly compromise functional recovery and prolong the rehabilitation process.

Another aspect frequently discussed in the literature refers to the risk of sural nerve injury during percutaneous procedures. Buchgraber and Passler⁽¹²⁾ reported a potentially higher incidence of sensory alterations than with open approaches. However, no cases of persistent paresthesia or neurological deficits were observed in this series. This result may reflect standardized surgical technique, adequate anatomical knowledge, and the team's experience performing the procedures.

The ATRS score showed satisfactory recovery of Achilles tendon function. These findings corroborate previous studies showing that minimally invasive techniques can deliver functional outcomes similar to or better than those observed with open techniques, especially when combined with structured rehabilitation protocols.

Early functional rehabilitation is an important component in the treatment of acute Achilles tendon ruptures. In a randomized clinical trial, Metz et al.⁽¹³⁾ compared minimally invasive surgical treatment with non-operative treatment, both associated with functional rehabilitation and immediate weight-bearing. No statistically significant differences were observed between the groups regarding the occurrence of complications or re-rupture. However, the return to work activities occurred earlier in the group undergoing minimally invasive treatment.

In the present study, the principles based on the protocol of Alfredson et al.⁽⁶⁾ were chosen for their broad clinical applicability, ease of execution, and good reproducibility in the outpatient setting. The association between minimally invasive repair and progressive eccentric strengthening of the triceps surae muscles contributed to the satisfactory functional outcomes observed during follow-up.

This protocol was also incorporated because pain and functional limitation can persist after open repair of an Achilles tendon rupture. Strauss et al.⁽¹⁴⁾, in a series of open repairs, observed that, despite favorable overall outcomes, 22% of patients still had some degree of pain and 26% reported

limitations in activities during late follow-up. In addition, the postoperative complication rate was 16.8%. Sikorski and Czamara⁽¹⁵⁾ showed that 15 weeks of physical therapy after open repair were necessary to restore independent, painless ambulation; however, plantar flexion and supination of the operated limb remained reduced compared with individuals without injury, suggesting incomplete functional recovery even after structured rehabilitation.

In this context, the principles of eccentric weight-bearing described by Alfredson et al.⁽⁶⁾ were adapted and incorporated into the strengthening phase for patients undergoing percutaneous repair with the Tenolig® device, to improve tendon tolerance to weight-bearing, reduce pain, and promote range-of-motion recovery. This strategy was adopted based on the literature, which describes residual pain, functional limitation, reduced mobility, and tendinopathic symptoms after open repair. This series showed good exercise tolerance and low pain-related limitation, although the lack of a comparator group does not allow establishing the superiority of the percutaneous technique over the open technique. Although the original protocol was developed for patients with chronic tendinosis of the middle portion of the Achilles tendon, its 12-week application significantly reduced pain during activities and improved muscle strength and return to the previous level of activity, providing a clinical basis for the progressive use of eccentric training. In the present study, this adaptation aimed to gradually increase tendon weight-bearing tolerance, reduce residual pain, and promote functional recovery during the postoperative period.

All patients performed the proposed monopodal functional exercise without relevant pain complaints, with a mean execution time of 31.8 seconds. These findings suggest good clinical tolerance for tendon weight-bearing after percutaneous repair, consistent with the rehabilitation protocol employed. However, because no group underwent open repair, the results cannot be attributed solely to eccentric strengthening or used to establish the percutaneous technique's superiority. Thus, the outcomes should be inter-

preted as descriptive evidence of the protocol's feasibility and clinical tolerability.

It was also observed that patients with less social support had greater difficulty in adhering to the physiotherapeutic protocol, a factor potentially related to functional recovery. Visser et al.⁽¹⁶⁾, in a study of patients with Achilles tendinopathy, identified an association between low socioeconomic status and less favorable therapeutic outcomes. Although tendinopathy and acute Achilles tendon rupture are clinically distinct conditions, these findings can be considered, in an exploratory way, to understand how socioeconomic factors influence treatment adherence and functional recovery.

Overall, the results of this series suggest that minimally invasive repair using Tenolig®, combined with a structured rehabilitation protocol, provides adequate functional recovery, low complication rates, and reduced incidence of re-rupture in the treatment of acute Achilles tendon ruptures.

The present study has important limitations, including a small sample size, a retrospective design, no control group, single-center performance, and the predominant use of subjective instruments for functional assessment. In addition, no complementary objective evaluations were performed, such as dynamometry, serial ultrasound, or comparative biomechanical analysis. Thus, interpret the results with caution; prospective, comparative studies with larger patient numbers are needed to better validate the findings.

Conclusion

The minimally invasive treatment of acute Achilles tendon rupture with the Tenolig® device, combined with a structured rehabilitation protocol with eccentric exercises adapted from the principles described by Alfredson et al.⁽⁶⁾, showed satisfactory functional outcomes and low complication rates in this case series. However, comparative prospective studies with larger patient numbers are needed to better validate the technique.

Authors' contributions: Each author contributed individually and significantly to the development of this article: JMM *(<https://orcid.org/0000-0001-6039-4599>) Conceived and planned the activities that led to the study and data collection; SDSP *(<https://orcid.org/0000-0002-8677-3981>) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, bibliographic review; MAGR *(<https://orcid.org/0000-0002-7424-9074>) Data collection; LGSL *(<https://orcid.org/0000-0002-1343-3687>) Data collection, interpreted the results of the study, participated in the review process; GCPA *(<https://orcid.org/0009-0000-3343-5201>) Data collection, revision of the selected references. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) 

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Original Article

Union rates in hallux interphalangeal joint arthrodesis: A retrospective review of a reproducible surgical technique

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Abstract

Objective: To assess the radiographic union rate and complications following hallux interphalangeal joint arthrodesis (HIPJA) using a single reproducible surgical technique and report on possible technique tips to improve the union rate.

Methods: A retrospective review of all HIPJAs performed by four foot and ankle orthopedic surgeons was conducted. The surgical technique, patient factors, indications, reoperation rate, complications, and radiographic evidence of arthrodesis were collected. Radiographic union was defined as two cortical continuations or trabecular bridging, absence of hardware failure, and the absence of lytic gapping at the arthrodesis site.

Results: Thirty-five primary HIPJA procedures were identified with radiographic follow-up until union or non-union was confirmed. Our cohort demonstrated a 97.1% radiographic union rate with a mean time to union of 20 weeks. There were three reoperations: two cases (5.7%; 95% CI, 0.7%-19.2%) for removal of painful hardware and one case (2.9%; 95% CI, 0.07%-14.9%) for revision of a symptomatic non-union. Because only one non-union occurred, the study was not powered to identify independent predictors of non-union.

Conclusion: This cohort showed a mean above-radiographic union rate with a consistent surgical technique, meticulous joint preparation, and a single large intramedullary differential pitch screw for fixation. Radiographic union took longer than expected, with a mean of 20 weeks.

Level of Evidence IV; Retrospective Case Series.

Keywords: Fractures, ununited; Arthritis, Joint arthrodesis.

Introduction

Hallux interphalangeal joint arthrodesis (HIPJA) has not received the same attention as the metatarsophalangeal joint (MTPJ) arthrodesis in the orthopedic literature. Although less common, it is mostly performed for pain, deformity, or dysfunction⁽¹⁾. This procedure can be performed as a standalone procedure in cases of primary, inflammatory, post-traumatic arthritis, or as part of the Jones procedure⁽²⁾ to treat clawing of the hallux and other angular deformities⁽³⁾.

Thorud et al.⁽⁴⁾ reviewed HIPJA fixation techniques, complications, and reoperation rates at four academic institutions

and reported significant differences in complication rates among the four institutions: 33%, 52%, 80%, and 90%, respectively. This large interinstitutional variation was attributed to differences in pre-operative patient health at each institution. The authors emphasized the importance of surgeon experience, hospital care, and postoperative protocols. Likewise, comparing the large cohorts in the studies by Thorud et al.⁽⁴⁾ (152 patients) and Braswell et al.⁽³⁾ (227 patients), complications differed significantly: Infection rates (16.5% vs 4%), wound dehiscence (12.5% vs 3.5%), and hardware removal (17.9% vs 6.6%). Thorud et al.⁽⁴⁾ reported that 5 of the 41(12%) revision surgeries ended in amputation.

Study performed at the Netcare Linksfield Hospital, Johannesburg, South Africa.

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Further research is needed to reduce complication rates and variability by identifying a standardized surgical technique—including approach, joint preparation, fixation, and postoperative protocol—that produces reproducible, favorable outcomes for HIPJA.

A recent study by Braswell et al.⁽³⁾ of 227 patients, the largest number of HIPJA at a single institution to date, again highlighted the difficulty of achieving union of the hallux interphalangeal joint (HIPJ) even with modern implants and techniques. They reported a 25.5% non-union rate, of which 53.4% of those patients required reoperation. In a systematic review by So et al.⁽⁵⁾, the non-union rate reached 28.3% in 313 HIPJAs⁽⁵⁾. This high reported non-union rate is concerning, and further research is required to improve outcomes.

The objective of this study is to assess the radiographic union rate and complications following hallux interphalangeal joint arthrodesis (HIPJA) using a single reproducible surgical technique and report on possible technique tips to improve the union rate.

Methods

A retrospective review was conducted on the surgical database to identify all consecutive patients who underwent primary HIPJA from 2008 to 2024 by a group of four foot and ankle surgeons using the same surgical technique. Inclusion criteria included patients older than 18 years, with complete clinical notes and adequate radiographic follow-up. A total of 35 patients met the inclusion criteria, with 16 males and 19 females, with a mean age of 55 years (range 18 to 74). No patients were excluded. Mean follow-up was 3.6 years; median follow-up was 1.2 years (IQR, 0.3-5.0 years), with a range of 0.2-17 years (Table 1). The study was conducted after approval by the Institutional Review Board.

Table 1. Patient demographics and comorbidities (n = 35)

Variable	Value
Mean age at time of surgery	55 (range 18-74) years
Follow-up	Mean: 3.6 (range 0.2-17) years Median: 1.2 (IQR, 0.3-5.0) years
Sex, n (%)	
Male	16 (46%)
Female	19 (54%)
Side	
Left	17 (49%)
Right	18 (51%)
Diabetes, n (%)	8 (23%)
Peripheral neuropathy, n (%)	10 (29%)
Neuromuscular condition, n (%)	9 (26%)
Inflammatory arthritis, n (%)	9 (26%)
Active tobacco use, n (%)	1 (3%)

IQR: Interquartile range.

All patients in our study were treated with the same surgical technique and postoperative protocol. An L-shaped incision is made across the interphalangeal joint on the dorsal skin and proximally along the medial border of the phalanx. An elliptical excision of excessive skin and capsule can be performed in flexion deformities over the interphalangeal joint (Figure 1). Meticulous soft tissue handling, with preservation of a full-thickness tissue flap and the use of blunt hand-held retractors, is of utmost importance. The capsule and extensor hallucis longus are cut transversely, leaving enough distal tissue for reattachment and closure. Once the joint is exposed, the proximal phalanx condyle is cut flat and perpendicular to the shaft of the proximal phalanx using an oscillating saw with irrigation, while protecting the soft tissue. The base of the distal phalanx is then carefully exposed, being aware not to injure the germinal zone of the nail bed. The base of the distal phalanx is then resected to achieve a reciprocal flat cut to match the proximal phalanx (Figure 2). In the setting of a varus or valgus malalignment, an appropriate wedge resection is taken from the proximal phalanx. In cases of severe contracture, the flexor hallucis longus tendon can be released through the prepared joint. The joint is then reduced to confirm correct alignment prior to fixation. The proximal and distal joint surfaces are then perforated using a

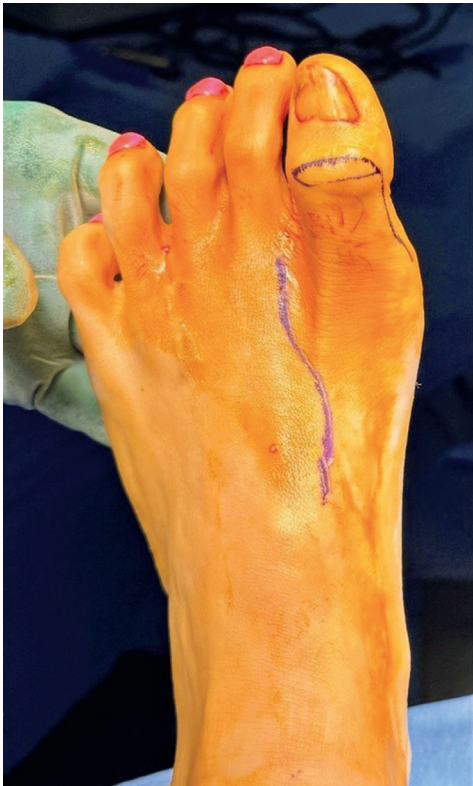


Figure 1. An L-shaped incision is made across the interphalangeal joint (elliptic excision of excessive skin can be done) and proximally along the medial border of the phalanx.

1.6 mm drill bit to allow marrow elements into the fusion site (Figure 3). Avoid using a guide wire, as it may cause thermal necrosis. The guidewire for fixation is then passed antegrade through the distal phalanx to exit at the central tip of the toe, clear of the nail bed. The joint is reduced to a neutral position in the sagittal plane with 0-5 degrees of valgus⁽⁶⁾, and the guidewire is advanced retrograde up to 4 mm from the MTPJ. A second wire can be placed to ensure rotational stability during preparation and screw insertion. The screw length is then measured, and a 4.5-5.5 mm differential-pitch titanium headless compression screw (4.7-5.5 mm Acutrak 2[®], Acumed, USA or 4.5-5.5 mm Monster[®] Screw Paragon 28 Inc, Englewood, CO, USA) is inserted, taking care to not injure the soft tissue at the tip of the toe. The screw head should be countersunk adequately to prevent irritation and achieve compression (Figure 4). Autogenous bone grafting is used selectively when a bone defect or concern regarding bone quality is identified intraoperatively. Autogenous bone graft is routinely harvested from the distal tibia when required and inserted prior to fixation. Our team prefers to routinely use autogenous bone rather than allograft bone. The wound is closed in layers. A wool and crepe bandage dressing is applied and the foot placed in a forefoot off-loader shoe for the first six weeks. The patients are advised to have strict bed rest and elevation for the first two weeks. Wound inspections are performed at week 1, 2 and 6. After six weeks, the patient may resume normal daily activities in supportive sports shoes and perform non-impact exercises such as cycling, yoga, pilates and swimming. High-impact exercises are resumed after 12 weeks based on radiographic union and symptoms.

Foot weight-bearing radiographs are performed at week 6, 10, 15, 20, and three-monthly thereafter until radiographic union or non-union is confirmed. Radiographic union was defined as two cortical continuations or trabecular bridging at the arthrodesis site, absence of hardware failure, and the absence of lytic gapping of the joint⁽³⁾. A non-union was defined as the absence of trabecular bony bridging at the

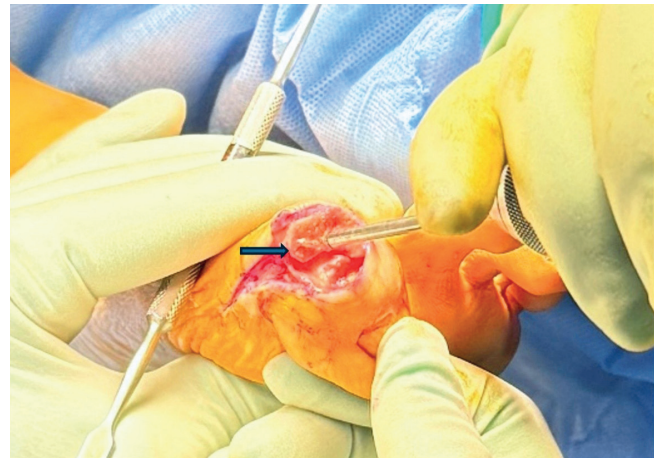


Figure 3. The prepared joint surfaces are then drilled using a 1.6 mm drill bit to form a vascular channel to allow bone marrow elements into the fusion site.



Figure 2. (A) The condyles of the proximal phalanx are exposed and the soft tissues protected with a McDonald dissector. (B) The condyles of the proximal phalanx of the hallux are excised using a small oscillating saw with irrigation. (C) The base of the proximal phalanx is carefully exposed so as not to damage the germinal layer of the nail bed. (D) The base of the distal phalanx is then resected to achieve a reciprocal flat cut to match the proximal phalanx.

fusion site and/or hardware failure after a minimum follow-up of six months⁽⁷⁾. All patient radiographs were independently reviewed by the authors, with reviewers blinded to clinical outcome data, to assess for fusion of the HIPJ. Interobserver reliability was not formally assessed, and disagreements were resolved by consensus. Clinical symptoms of a possible non-union included persistent swelling, erythema, and pain at the fusion site, which were documented if present. All reported complications were documented. Patient demographics, tobacco use, and comorbidities were collected from clinical records and recorded. All associated procedures and prior ipsilateral hallux MTPJ fusion were documented.

For statistical analyses, continuous variables were summarized using means and standard deviations and medians with interquartile ranges. Categorical variables were summarized using frequencies and percentages. The primary outcome was radiographic union. Given the small cohort size and the single non-union event, the analysis was primarily descriptive with no multivariable modeling possible. An exact 95% confidence interval was calculated for the observed union proportion.

Results

Patient co-morbidities, tobacco use, ipsilateral MTPJ fusions, and additional procedures are reported in Table 1 and Table 2. The indications for HIPJA are summarized in Table 3.

Radiographic union was achieved in 34 of 35 procedures (97.1%; 95% CI, 85.1%-99.9%). Three patients (8.6%; 95% CI, 1.8%-23.1%) underwent reoperation. One patient (2.9%; 95% CI, 0.07%-14.9%) developed a non-union. Given the small, heterogeneous cohort and single non-union, the study was underpowered for multivariate analysis to assess potential risk factors for developing a non-union. The non-union occurred in a 72-year-old male non-smoker known with

gout, hypothyroidism, and neuropathy who had IPJ arthritis secondary to gout. An identical surgical technique was utilized, but a 4 mm Paragon 28 Mini-monster® screw was used at the initial surgery. He was noted to have florid gouty crystals throughout the joint at the time of primary surgery despite medical treatment. The patient presented at 28 weeks with a painful non-union and was subsequently revised to a larger screw with autogenous bone grafting. He achieved union at 24 weeks after the revision surgery (Figure 5). Two cases (5.7%; 95% CI, 0.7-19.2%) required reoperation

Table 2. Associated procedures and prior MTPJ fusion

Associated procedures	
Lesser toe correction	10 (29%)
Bunionette correction	2 (6%)
Ankle instability ligament reconstruction	2 (6%)
Previous MTPJ fusions	5 (14%)

MTPJ: Metatarsophalangeal joint.

Table 3. Indications for HIPJA

Indication	n (%)
Angular deformity	16 (46%)
Inflammatory arthritis	9 (26%)
Post-traumatic arthritis	4 (11%)
Primary osteoarthritis	3 (9%)
Charcot arthropathy	2 (6%)
Post-infective arthritis	1 (3%)
Total	35 (100%)

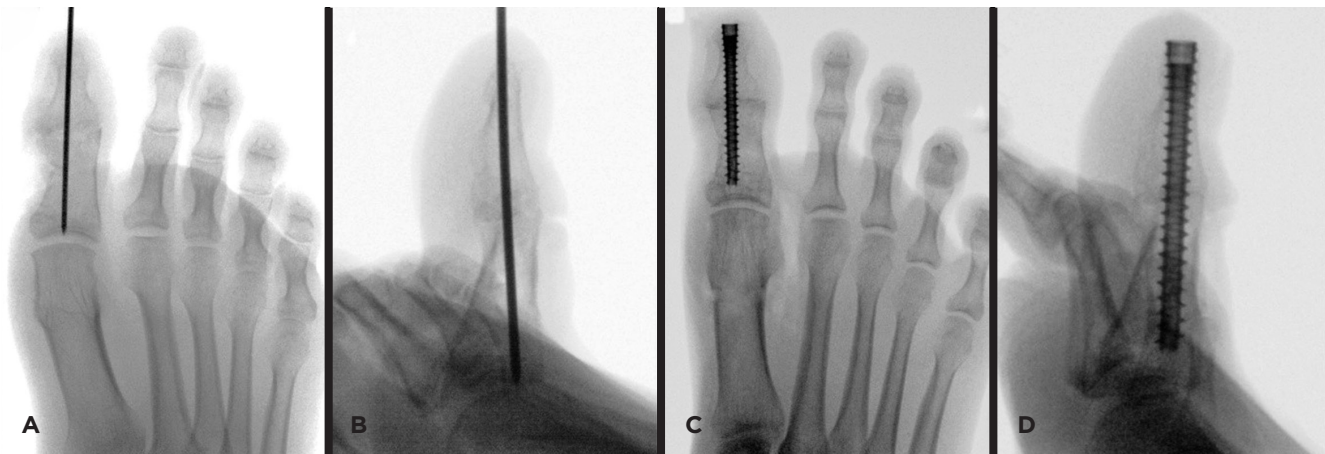


Figure 4. (A-B) Intra-operative fluoroscopic anteroposterior and lateral view of the hallux showing reduction of the prepared interphalangeal joint and placement of the guidewire in the center of the phalanges. (C-D) Intra-operative fluoroscopic anteroposterior and lateral view of the hallux showing fixation of the interphalangeal joint with a 4.5-5.5 mm differential-pitch titanium headless compression screw, achieving good compression.

for screw removal due to symptomatic hardware irritation after confirmed union. Notably, only 20% (7/35) of patients achieved union before week 15, and the mean time to union

was 20 weeks or longer (Figure 6 and 7). Autogenous bone grafting was performed in 2 of 35 procedures (5.7%), primarily in cases with bone defects (Table 4).



Figure 5. (A) Patient with symptomatic non-union at 28 weeks. (B) Patient achieved union 24 weeks after revision with a larger screw and autogenous bone grafting.



Figure 6. Radiographs of three patients showing no clear union at 10 weeks after surgery.



Figure 7. The same three patients at final follow-up showing union at 80, 208, and 216 weeks, respectively.

Discussion

The high reported incidence of non-union of HIPJA is concerning, with little guidance in the literature on preventing this complication. Complications after HIPJA are multifactorial and should be assessed and addressed accordingly. The complication most consistently reported as unacceptably high is non-union, which ranges from 25%-30%^(4,5). Our long-term follow-up study showed a non-union rate of only 2.9%. It is important to identify possible factors that may improve the union rate of HIPJA. In our sample, two patients (5.7%; 95% CI, 0.7%-19.2%) underwent reoperations for symptomatic hardware, both of which had screw removal after confirmed union. One patient (2.9%; 95% CI, 0.07%-14.9%) required fusion revision for a symptomatic non-union. Overall, our 8.6% (3/35) reoperation rate compares favorably with the literature (21%-27%)^(3,4).

The indication for doing a HIPJA has been reported to play an important role as a risk for developing a non-union. Braswell et al.⁽⁴⁾ reported that deformity correction had a higher risk of developing a non-union than arthritis or trauma. Deformity correction was the most common indication in our study (16/35), with all cases achieving a successful union. The one non-union in our cohort had secondary arthritis due to

poorly controlled gout. Thitiboonsuwan et al.⁽⁸⁾ reported that prior adjacent hallux MTPJ fusion increases time to union by 4.8 times and the risk of non-union due to increased weight-bearing on the IPJ post-MTPJ fusion^(3,8,9). Five patients with prior ipsilateral hallux MTPJ fusion achieved a successful union.

Soft tissue handling, joint preparation, and fixation device/technique are surgeon-related factors that contribute to successful HIPJA and are within the surgeon's control^(4,10). Derner and Meyr described V-shaped cuts for joint preparation, which increase contact surface area for fusion and provide intrinsic frontal-plane stability, although they are technically more demanding. Oblique screws would be placed perpendicular to the cut surfaces, avoiding the proximity of the nail bed, but at the cost of using a smaller screw⁽¹¹⁾. In our opinion, this technique is technically demanding to perform without compromising the soft tissue and germinal layer of the nail bed when preparing the distal phalanx. We prefer flat cuts and routinely use a small oscillating saw with saline irrigation to minimize thermal necrosis for joint preparation.

Multiple fixation methods have been described since the original description of K-wire fixation, which resulted in unacceptably high non-union rates (32%-44%)^(5,10). Modern fixation methods include compression staples and single or double screw fixation with reportedly improved success in achieving union^(4,12). A systematic review by So et al.⁽⁵⁾ has shown that single screw fixation resulted in improved union rates and fewer infections as compared to K-wire fixation. Cross screw configurations had significantly higher wound dehiscence, infections, and reoperations, but fairly similar union rates in a study by Thorud et al.⁽⁴⁾ Hyer et al.⁽¹²⁾ reported that using two parallel 3 mm headless screws had a higher rate and shorter time to fusion as compared to a single 4 mm screw. Despite the reported improvement in union rate with modern fixation devices, the reported non-union rate is still as high as 30%, which is exceptionally high by modern-day standards (Table 5)^(3,5). The optimal screw size for fixation of

Table 4. Summary of screws used, bone grafting and reoperations

Variable	n / n	Percentage
Screws used		
4.7 mm Acutrak screw	31 / 35	88.6%
4.0 mm Paragon Mini Monster screw	4 / 35	11.4%
Autogenous bone grafting	2 / 35	5.7%
Reoperations	3 / 35	8.6%
Removal of symptomatic hardware	2 / 35	5.7%
Revision for non-union	1 / 35	2.9%

Table 5. Summary comparing fixation constructs and union rates in the literature

Study	Fixation construct	No. of HIPJA	Union rate	Non-union rate
Shives and Johnson, 1980	K-wire	101	56%	44%
Shives and Johnson, 1980	Longitudinal mini-cancellous compression screw	20	90%	10%
Thorud et al., 2016	Single intramedullary screw	74	77%	23%
Thorud et al., 2016	Crossed screws	13	76.9%	23.1%
Thorud et al., 2016	K-wire	10	40%	60%
Hyer et al., 2017	Single 4.0 mm intramedullary screw	7	71.4%	28.6%
Hyer et al., 2017	Two 3.0 mm headless intramedullary screws	32	78.1%	21.9%
So et al., 2018	K-wire fixation, pooled literature	158	67.7%	32.3%
So et al., 2018	Single-screw fixation, pooled literature	121	84.3%	15.7%
So et al., 2018	Crossed-screw fixation, pooled literature	17	82.4%	17.6%
Braswell et al., 2023	Predominantly single screw fixation ± additional fixation	227	74.5%	25.5%
Present study	4.7 mm Acutrak screw (31/35) or 4.0 mm Paragon screw (4/35)	35	97.1%	2.9%

HIPJA: Hallux interphalangeal joint arthrodesis.

the HIPJA has not been assessed in the available literature^(4,6). In our case series, the non-union was fixed with only a 4 mm screw, which may have contributed to failure due to inferior stability. Since the most common technique is a single screw fixation of a flat cut (poor rotational stability) joint surface, using a larger screw may add additional compression and stability to the fusion site^(4,6). Some authors have suggested revising the non-union cases with a larger screw⁽¹³⁾. We now routinely use at least a 4.5 mm screw with a variable pitch, which may give better compression at the fusion site than a standard fully or partially threaded screw. In larger patients or revision cases, we try using a 5.5 mm or larger screw if we can safely insert the screw without risk of fracturing the distal phalanx (Figure 5).

Smoking⁽¹⁴⁻¹⁷⁾, diabetes⁽⁴⁾, obesity⁽⁴⁾, and peripheral neuropathy⁽⁴⁾ are patient factors that could impact union or reoperation rates. Modifiable patient risk factors have been assessed in the literature, but no correlation has been identified with non-union rate. In our study, although a much smaller sample size (35 patients), the incidence of diabetes was 23% (8/35) and peripheral neuropathy was 29% (10/35), similar to other larger studies such as Braswell et al.⁽³⁾ and Thorud et al.⁽⁴⁾ (23% and 32%, respectively). The incidence of active smokers was also not significantly different (2.9% vs 6.2%). Our patient with the non-union was a non-smoker but had neuropathy due to spinal pathology. Due to the small cohort, we are unable to comment on the correlation between comorbidities and the risk of developing a non-union. Patient compliance with postoperative protocols is also important for achieving a successful union; however, this factor is outside the surgeon's control, except by educating the patient about its importance. Unfortunately, it is not possible to measure and report compliance once the patient is at home.

Based on our outcomes and the available literature, we suggest the following to help reduce the incidence of HIPJA non-union. Regarding the surgical technique: practice meticulous soft tissue handling, ensure adequate exposure (L-shaped incision instead of an isolated elliptical incision over IPJ) to allow for good joint preparation, drill the joint surface with a 1.5-2 mm drill, and bone graft any voids with autogenous bone graft. Consider using the largest differential pitch headless compression screw, which can be safely inserted without compromising the phalanx, to

achieve optimal compression and stability. Post-operatively immobilize the foot in a non-weight-bearing forefoot shoe for six weeks.

Our study showed that radiographic union can take longer than expected (a mean of 20 weeks or more), as reported by Thitiboonsuwan et al. (8). If the patient is asymptomatic, follow up for six months before diagnosing a non-union. Studies have reported that 47%-74% of patients with fibrous unions had acceptable patient-reported outcome scores and did not require revision^(5,9). Some of these reported asymptomatic non-unions had short follow-up, and if these patients were followed longer, radiographic union may have occurred.

Limitations of this study include its retrospective nature, a relatively small cohort size, and lack of patient-reported outcomes after the HIPJA. Radiographic assessment was performed retrospectively by the authors. The small cohort, heterogeneous indications, and only one non-union event do not allow multivariable analysis to assess potential risk factors for non-union. This retrospective review was performed due to the concerning high reported non-union rate of HIPJA. The lack of prospective, large studies, together with the reported high incidence of non-union, emphasizes the need for more research on this topic, including patient-reported outcomes and multivariable analysis to further evaluate clinical outcomes and risk factors for non-union following HIPJA. Our hope is that this study will stimulate further research.

Conclusion

The non-union rate of the hallux interphalangeal joint arthrodesis ranges from 0% to 43%⁽³⁾, while the incidence of non-union in other foot joints is usually less than 13%⁽¹⁸⁻²⁰⁾. Although not all non-unions require revision, it remains a concern⁽³⁾. This retrospective case series had a 97.1% radiographic union rate using a reproducible surgical technique consisting of meticulous joint preparation and fixation using a single large intramedullary differential pitch screw. Radiographic union took longer than expected, with a mean of 20 weeks. Larger prospective comparative studies incorporating patient-reported outcomes are required to assess risk factors associated with HIPJA non-union.

Authors' contributions: Each author contributed individually and significantly to the development of this article: FJ *(<https://orcid.org/0000-0001-7045-1681>) Assisted with surgeries, data collection, interpreted the results of the study, bibliographic review, survey of the medical records, formatting of the article, and approved the final version; JJ *(<https://orcid.org/0000-0003-1448-4272>) Interpreted the results of the study, participated in the review process, performed the surgeries, formatting of the article, and approved the final version; MW *(<https://orcid.org/0000-0002-7999-9069>) Performed the surgeries, participated in the review process, formatting of the article, and approved the final version; NP *(<https://orcid.org/0000-0002-5566-7588>) Interpreted the results of the study, participated in the review process, performed the surgeries, formatting of the article, and approved the final version; PN *(<https://orcid.org/0000-0003-4639-0326>) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, performed the surgeries, formatting of the article, and approved the final version. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) .

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Case Report

An unusual presentation of multiple metatarsophalangeal joint irreducible dislocation: A case report

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Abstract

Dislocations of multiple metatarsophalangeal joints are a rare injury, as the compact arrangements of tissues around the joint make it a stable condyloid joint. There are a few cases in the literature showing four or all metatarsophalangeal dislocations. We present a case of a male patient who sustained a fall from height resulting in dorsiflexion injury of the metatarsophalangeal joint. Closed reduction techniques failed; therefore, we had to perform an open reduction of the dislocation. Two dorsal incisions are used to address the injury. It was found that the plantar plate and buttonholing of the capsule prevented its reduction. A dorsal approach prevents further injury to the plantar plate, but the capsule had to be incised to achieve reduction.

Level of Evidence V; Case Report.

Keywords: Foot injuries; Multiple metatarsophalangeal joint; Fracture dislocation; Open fracture reduction.

Introduction

The metatarsophalangeal joints consist of the synovial condyloid joint in which the metatarsal heads articulate with the phalanges. Their anatomy is similar to the metacarpophalangeal joints of the hand. The metatarsophalangeal synovial joint is covered by a fibrous capsule and strengthened by collateral ligaments. Additional support comes from the extensor tendons on the dorsal side and the fibrous plantar plates on the plantar side⁽¹⁾. To note, the plantar plate type 1 collagen composition is similar to that of the meniscus in the knee and the annulus fibrosis in the intervertebral disc. The metatarsophalangeal joint allows a range of motion in flexion, extension, and some abduction and adduction⁽²⁾.

The hallux metatarsophalangeal joint is stabilized by its capsule and the ligaments surrounding the tendons. The stabilizing components are the fibrous capsule, the collateral ligament complex, the sesamoid-phalangeal ligaments, the inter-sesamoid ligament, the plantar plate, and the extensor hood. The surrounding tendons crossing the joint, the flexor

hallucis brevis and longus, abductor and adductor hallucis, and extensor hallucis brevis and longus, provide additional stability. There is documented variability in sesamoid anatomy and configuration.

The anatomical stability from the second to the fifth metatarsophalangeal joints is provided by the fibrocartilage ridge, the plantar plate, approximately 2cm in length and 2mm in thickness, and rectangular in shape⁽³⁾. The plantar plate arises from the plantar side of the metatarsal and is inserted into the plantar aspect of the proximal base of the phalanx. Additional stability is provided by the collateral ligament, accessory collateral to either side, the medial and lateral collateral ligaments, and the deep transverse intermetatarsal ligaments. The collateral ligaments originate from the distal tubercle of the metatarsal and are inserted into the proximal part of the inferior side of the proximal phalanx on the medial and lateral sides, respectively. Accessory collateral ligaments originate along with the dependent portion of the collateral ligament and are inserted into the plantar plate. The lateral

Study performed at the SP Medifort Hospital, Trivandrum, Kerala, India.

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collateral ligament was found to be thicker and stronger than the medial collateral ligament (Figure 1).

The compact arrangement of capsule, fibrous covering, ligamentous complex, flexor and extensor tendons makes the metatarsophalangeal joint a stable joint with good range⁽⁴⁾. To dislocate a metatarsophalangeal joint, there should be a violent, high-velocity injury force.

Case presentation

We present the case of a 31-year-old active male who sustained a fall from a height of around 30 feet and landed on his foot. His history revealed that he landed on his forefoot with dorsiflexion force. He was received in the emergency

room 90 minutes post-injury. Primary evaluation showed a chest injury and pneumothorax. Intercostal drainage was inserted, and the patient was admitted to the critical care unit. His right foot revealed gross deformity at the forefoot level with a wound over the medial aspect of the hallux and the plantar aspect of the base of the second toe. Initial trauma protocol radiographs showed dislocation of the first through fourth metatarsophalangeal joints of the right foot with no associated fractures. A trial of closed reduction was attempted under sedation and muscle relaxation, but was unsuccessful. After wound irrigation, a splint was applied, and a computed tomography was performed for further evaluation of the metatarsophalangeal injury (Figures 2 and 3).

After clinical and radiological evaluation, the patient was scheduled for closed or open reduction under general anesthesia once the general condition stabilized. On post-injury day 2, the patient was scheduled for the procedure, and assistance from the plastic surgery team was requested (Figure 4).

Intraoperative findings: After skin incision, the tendons retracted along with the sheath. The metatarsal head was not reducing due to obstruction from the plantar plate and capsule. The capsule is incised, and the plantar plate is levered under the metatarsal. The levered metatarsal head is reduced to the phalanx base. The reduced joint is unstable because capsule support is lost (Figures 5 and 6).

The third metatarsal fracture was stable and was checked under C-arm; hence, it was planned for conservative management. After successful reduction and fixation of the first through fourth metatarsophalangeal joints, the incised capsule was repaired with 3-0 Vicryl.

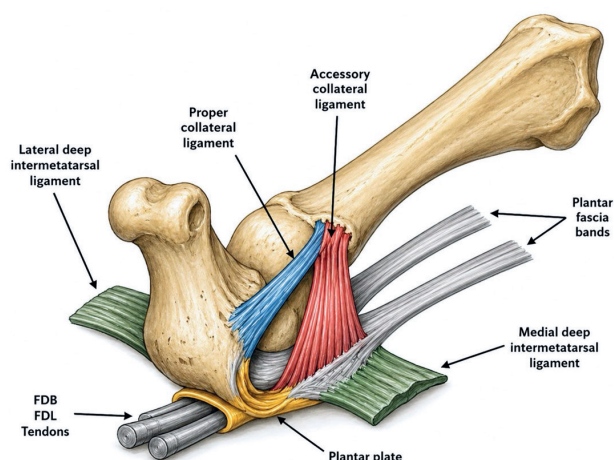


Figure 1. Anatomy of the metatarsophalangeal joint.



Figure 2. Illustration of the deformity noted along the base of the toes (plantar, dorsal, and side aspects). The blue-marked area-metatarsal head is palpated. Lacerated wound over the medial aspect of the hallux at the metatarsophalangeal joint. The medial structures are disrupted, and metatarsophalangeal reduction can be palpated but unstable.

The medial stabilizing structures of the hallux were approximated and sutured before skin closure. The skin was closed with loose nonabsorbable sutures, and a below-knee plaster cast was applied. Wound inspection on postoperative days 2 and 4 showed a clean wound.

The patient was discharged on postoperative day 4. The plan was to leave the K-wires and the cast for eight weeks and to start weight-bearing after 12 weeks. Also, serial radiographs are recommended at 1, 2, 3, 4, and 6 months follow-up (Figure 7).

Discussion

The metatarsophalangeal joint is one of the most stable joints in the body, yet it takes immense force during the gait cycle. Simultaneous push-off from all five rays is needed for normal gait. The stability described is provided by the surrounding structures.

It needs violent force to dislocate multiple metatarsophalangeal joints. A missed or inappropriately treated metatarsophalangeal dislocation can lead to abnormal gait and persistent pain.



Figure 3. Radiographs and computed tomography showed the subluxed, unstable hallux metatarsophalangeal joints and plantarly dislocated second, third, and fourth metatarsals. Base of the third metatarsal fracture. The fifth metatarsophalangeal joint is reduced.

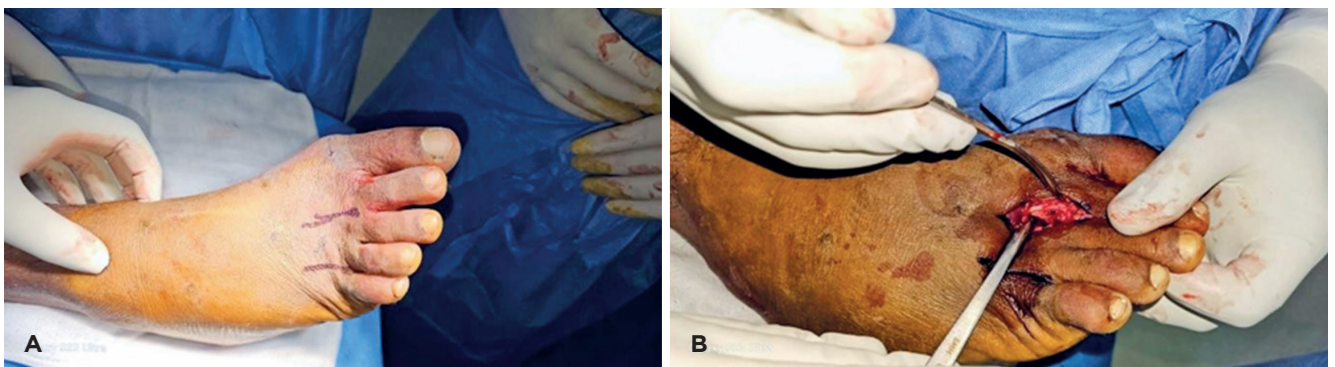


Figure 4. (A) Planned incision between the second and third toes and between the fourth and fifth toes. The hallux reduction can be palpated through an open wound. (B) The metatarsal is elevated using a lever, the plantar plate is levered under the metatarsal, and the capsule had to be incised to reduce the joint.



Figure 5. Initial levering of the metatarsal head did not reduce it due to obstructions from the plantar plate and capsule.

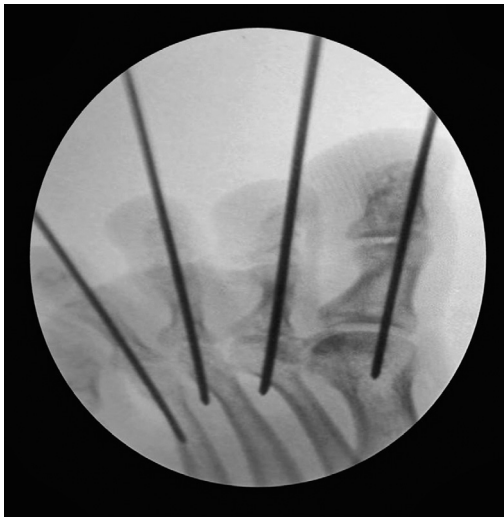


Figure 6. Open reduction and each metatarsophalangeal joint reduction is visually confirmed, and one axial K-wire is inserted in a slight dorsiflexed position.

This case was particularly challenging because it involved an unusual injury pattern with failed closed reduction. Metatarsophalangeal joint dislocations are usually reduced in the emergency room under sedation or muscle relaxation with closed manual reduction⁽⁵⁾. When dislocations are irreducible,



Figure 7. Postoperative anteroposterior and oblique radiographs.

surgeons often need to consult the literature and seek peer input for further management. To date, very few similar cases have been reported, with fewer than five describing dislocation of the first through fourth metatarsophalangeal joints⁽⁶⁾.

In a few cases in the literature, multiple dislocations required open reduction and temporary internal fixation using K-wires. Dorsal incisions are used for exploration and reduction in which the plantar plate or transverse metatarsal ligament was found to be obstructing the reduction. A plantar approach is also described in the literature, allowing reduction and repair of the plantar plate. The plantar plate repair will stabilize the joint and may not require an additional K-wire for stabilization^(7,8). In our case, K-wires are used for stabilizing the joint. The order of reduction is not cited anywhere; we reduced the second metatarsophalangeal joint and followed the same technique through the fourth joint. The hallux metatarsophalangeal joint is fixed last, with disruption of the medial supporting structures, resulting in joint subluxation.

Multiple metatarsophalangeal joint closed dislocations are a very rare injury. Initial management is by closed reduction under anesthesia. Joint reduction is established by correction of gross deformity, anteroposterior and oblique view radiographs. If closed reduction fails, open reduction is advised. Dorsal incision is used over the joint. The structures that prevent reduction include the plantar plate, the transverse metatarsal ligaments, and the capsule. These structures may need to be incised for reduction and repaired afterward. If the joint is unstable after reduction and repair, a K-wire temporary stabilization is advised.

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Case Report

Medial naviculocuneiform fracture-dislocations: A report of two cases

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Abstract

Medial naviculocuneiform fracture-dislocation – classified as a type B1 Lisfranc injury according to the Hardcastle classification modified by Myerson, or perhaps more accurately termed a 'Lisfranc-like medial column injury extending to the naviculocuneiform joint' – is an uncommon pathology. Available evidence is limited, with only a few cases reported in the literature. We present two cases of medial naviculocuneiform fracture-dislocation treated with different surgical techniques. The first case presented acutely and was managed with rigid fixation using cannulated screws. In contrast, the second case underwent primary arthrodesis due to a prolonged time since the injury and articular damage. Both patients were followed clinically and radiographically for 12 months. At the final follow-up, the acute case demonstrated an American Orthopaedic Foot and Ankle Society (AOFAS) midfoot score of 70/100 and a visual analog scale (VAS) score of 4/10, but with early osteoarthritic changes. In contrast, the delayed presentation case achieved an AOFAS midfoot score of 85/100 and a VAS score of 2/10.

Level of Evidence IV; Case Report.

Keywords: Fracture fixation, internal; Arthrodesis; Treatment outcome.

Introduction

Lisfranc injuries are infrequent, and according to the series by Stødle et al.⁽¹⁾, the incidence is 14/100,000 person-years, with only 31% resulting from high-energy trauma. The Hardcastle classification, modified by Myerson, categorizes injuries based on joint congruity, direction of displacement, and extent of involvement⁽²⁾. Type B1 injuries result in a partial incongruity of the tarsometatarsal joint, affecting only the first metatarsal and the medial cuneiform. However, some cases may also compromise the intercuneiform and naviculocuneiform joints, presenting with isolated medial dislocation. Characteristically, the remaining metatarsals maintain congruency with the rest of the midfoot⁽³⁾.

Cases with isolated involvement of this medial column of the foot have been rarely described. This report describes two cases of medial naviculocuneiform fracture-

dislocation, including their initial diagnosis, management, and 12-month follow-up. Importantly, the novelty of this study is that the same unusual injury pattern was treated with two distinct surgical strategies. The choice of fixation in Case 1 was influenced by the acute presentation, whereas primary arthrodesis was selected in Case 2 due to delayed presentation and concomitant articular degeneration at the naviculocuneiform joint.

Case presentation

Case 1

A 38-year-old female patient with no relevant prior medical history was brought to the emergency department after a motorcycle accident in which she collided with another vehicle, sustaining trauma to her right foot. Physical examination revealed moderate edema, pain, and ecchymosis

Study performed at Hospital Alma Máter de Antioquia, Medellín, Colombia.

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on the dorsum of the midfoot, along with a palpable bone deformity. Ecchymosis was also present on the ipsilateral hallux. Initial plain radiographs of the foot showed a proximal and medial dislocation of the first ray at the naviculocuneiform joint. The fracture-dislocation of the ipsilateral hallux at the interphalangeal joint with condylar fracture of the proximal phalanx was also evident (Figure 1). Advanced imaging, such as a computed tomography (CT) scan, was omitted as the patient required emergent surgical intervention. To prevent neurovascular compromise and soft-tissue complications, the patient was taken directly to the operating room for immediate closed reduction. Postoperative radiographs confirmed the correction of the deformities as a damage control measure (Figure 2).

Two weeks later, after the edema had resolved, the medial column was fixed in the operating room using 3.5mm cannulated screws that crossed the intercuneiform and naviculocuneiform joints, serving as a temporary fixation method while preserving the articular cartilage. A miniopen surgical approach was employed directly to the intercuneiform and naviculocuneiform joints. Reduction was achieved with a Weber clamp under direct visualization and fluoroscopic control to verify a congruent reduction. The previously performed percutaneous fixation of the hallux was removed. The patient was discharged home with a bulky bandage and instructed to avoid weight-bearing. At the two-week postoperative visit, the sutures were removed, the follow-up radiograph showed adequate reduction and fixation, and the hallux fracture-dislocation remained stable (Figure 3).

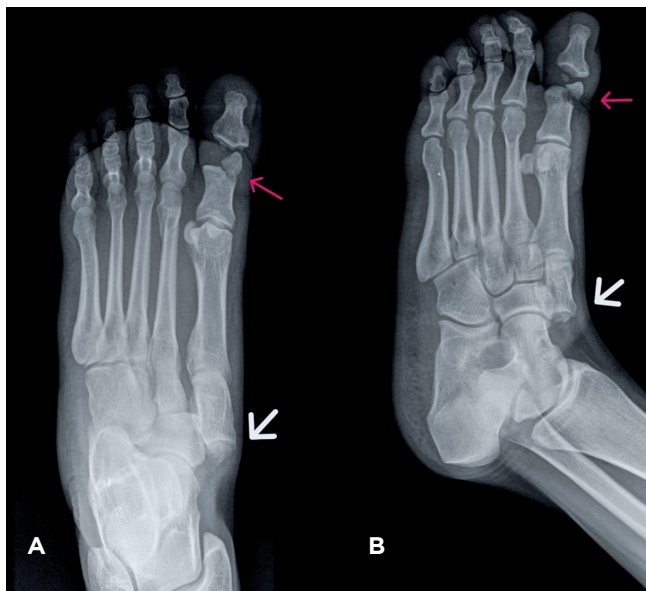


Figure 1. Anteroposterior (A) and oblique (B) radiographs of the right foot, demonstrating the naviculocuneiform fracture-dislocation with medial and proximal displacement (white arrow). Interphalangeal fracture-dislocation of the hallux with condylar fracture of the proximal phalanx (red arrow).



Figure 2. Anteroposterior (A), lateral (B), and oblique (C) radiographs show adequate reduction with K-wires of the naviculocuneiform and hallux fracture-dislocation, as a damage control measure.



Figure 3. Fixation was performed using 3.5mm cannulated screws, as shown in the oblique (A) and anteroposterior (B) radiographs, with screw trajectories extending from the navicular to the first cuneiform, across the intercuneiform region, and from the medial cuneiform to the navicular. There is progressive consolidation of the hallux condylar fracture, without evidence of loss of reduction. The naviculocuneiform alignment remains satisfactory on the lateral projection (C).

The patient initiated a structured physical therapy program incorporating progressive, protected nonweightbearing restrictions. She gradually transitioned through partial weightbearing stages as the soft tissues demonstrated clinical improvement and radiographic evaluations confirmed fixation stability, ultimately achieving full weight-bearing without external support at 16 weeks postoperatively. At 24 weeks, she was briskly walking and working as a gardener with footwear incorporating a medial scaphoid lift. At 10 months, routine removal was planned because the screws crossed mobile joints. After 12 months, the patient achieved a score of 70/100 on the American Orthopaedic Foot and Ankle Society (AOFAS Midfoot Score) scale, and a score of 4/10 on the Visual Analog Scale (VAS). For the hallux, the score on the AOFAS hallux metatarsophalangeal-interphalangeal score was 82/100. Radiographs obtained at 12 months postoperatively demonstrated early signs of midfoot osteoarthritis, along with subtle collapse of the medial longitudinal arch (Figure 4).

Case 2

A 50-year-old female patient presented to the emergency department 24 days after sustaining an inversion injury to the right ankle following a fall down the stairs. The patient presented with persistent pain, midfoot deformity, and limping. Upon admission, initial plain radiographs of the foot and ankle revealed a naviculocuneiform joint dislocation

associated with a fracture at the base of the first cuneiform (Figure 5). Given the delayed presentation and the presence of a fracture-dislocation, open reduction and primary arthrodesis was selected as the surgical treatment; a CT scan was not performed due to these clinical findings. The patient was taken to the operating room under general anesthesia, and using an anteromedial approach between the anterior and posterior tibialis tendons, the articular cartilage of the first and second cuneiforms as well as the navicular facet were evaluated, revealing erosion, fragmentation, and impaction. Articular scarification of the intercuneiform and naviculocuneiform joints was performed, followed by subchondral bone drilling. An autologous bone graft harvested from the calcaneus was applied to enhance fusion, and reduction of the cuneiform dislocation was achieved under direct visualization. Fixation was achieved with a 3.5 mm partially threaded cannulated screw between the navicular and first cuneiform by using the lag technique, and a bridge plate between the navicular and first metatarsal, to supplement compression at the arthrodesis site. The wound was closed in layers, and a bulky dressing was applied. The patient was discharged with analgesia and non-weight-bearing.

Two weeks after surgery, the wounds were evaluated, and sutures were removed. A follow-up radiograph showed adequate reduction and fixation (Figure 6). The patient initiated a physical therapy program to improve mobility, and progressive, protected weight-bearing in a CAM walker



Figure 4. Weight-bearing radiographs at 12-month follow-up. Comparative anteroposterior radiograph (A) with adequate alignment, slight changes of intercuneiform osteoarthritis in the right foot. Right lateral radiograph (B) with minimal decrease of the calcaneal pitch (26°), with respect to the left lateral radiograph (C), with normal angle (30°).

boot was permitted at week 12, only after the soft tissues demonstrated improvement of edema, there was no pain at the arthrodesis site, and radiographic evaluations confirmed construct stability. At nine months postoperatively, hardware

removal was performed due to symptoms from prominence beneath the skin and evidence of breakage observed during radiographic follow-up (Figure 7).

After 12 months from her index surgery, the patient achieved an AOFAS midfoot score of 85/100 and VAS of 2/10. She resumed her household duties, and the patient did not require the use of orthopedic shoes.

Discussion

According to the Hardcastle classification, as modified by Myerson, type B1 injuries correspond to partial incongruity of the medial column, specifically involving the first metatarsal and the medial cuneiform. The inter and intraobserver reliability of this system has been validated in several studies, making it useful in clinical practice⁽⁴⁾. These type B1 injuries with naviculocuneiform extension therefore represent Lisfranc-like medial column injuries, rather than typical tarso-metatarsal Lisfranc injuries (Figure 8).

They are uncommon; the literature reports very few cases over several decades, limiting the available evidence (Table 1)⁽⁵⁻¹⁰⁾. Regarding reduction and fixation methods, both closed and open reduction with K-wires have demonstrated good medium term clinical outcomes in acute cases without associated fracture, although mild arthritic changes have been reported^(5,8,9). Rigid internal fixation with 3.5mm cannulated screws has shown superior stability compared to K-wires, with favorable clinical results⁽⁷⁾. Bridge plating can maintain reduction; however, complications such as loosening and the need for revision have been described⁽⁹⁾. Primary arthrodesis, in cases with evident cuneiform and/or navicular joint injury, has yielded satisfactory outcomes after 18 months of follow-up⁽⁶⁾. In situations of nonunion of cuneiform fractures or

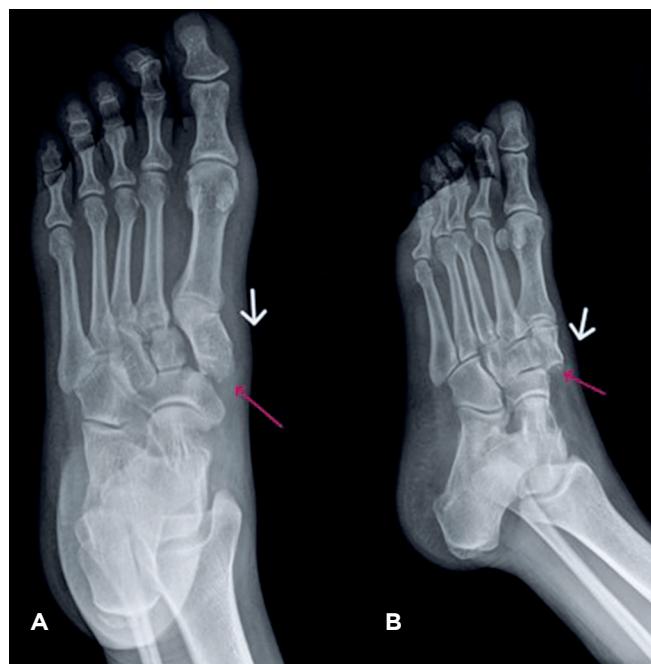


Figure 5. Anteroposterior (A) and oblique (B) radiographs of the right foot showing proximal and medial naviculocuneiform dislocation (white arrow). Fracture at the base of the first cuneiform (red arrow).



Figure 6. Oblique (A), anteroposterior (B), and lateral (C) radiographs with adequate reduction in all planes using a 3.5 mm screw and a bridge plate between the navicular and first metatarsal, for naviculocuneiform arthrodesis.



Figure 7. Radiographic control at nine months after material removal. (A) Comparative anteroposterior radiograph with adequate alignment of the midfoot and forefoot. (B) Oblique radiograph of the right foot shows complete consolidation of the intercuneiform and naviculocuneiform arthrodesis. (C and D) Comparative lateral weight-bearing radiographs of the feet, without longitudinal arch collapse, and with a remnant of broken intraosseous screws in the right foot.

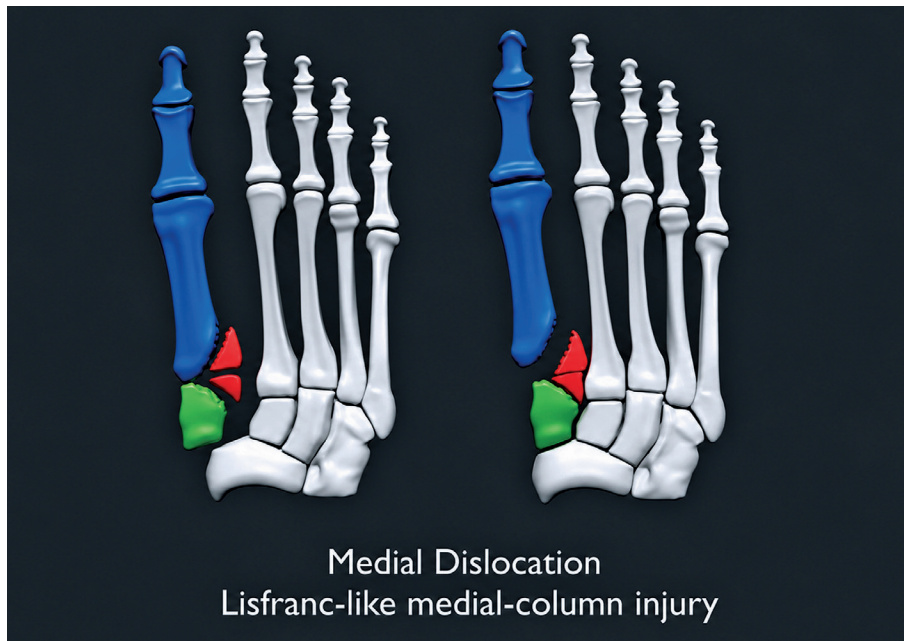


Figure 8. Type B1 injuries (partial incongruity of the medial column, specifically involving the first metatarsal and the medial cuneiform; these represent Lisfranc-like medial column injuries with naviculocuneiform extension), in the Hardcastle classification modified by Myerson. (Schematic educational illustration 3D modeling, created specifically for this manuscript. Courtesy and permission for use confirmed by Juan Fernando Romero Rosero).

Table 1. Review of cases reported in the literature

Reporting of previous cases	Number of patients	Age	Mechanism of trauma	Type of injury	Open/closed reduction	Tracking	AOFAS midfoot score / VAS scale
Dines et al. ⁽⁶⁾	1	37-year-old	Foot slammed onto brake pedal of car	Isolated dorsomedial dislocation of the medial cuneiform and first ray at the medial naviculocuneiform joint	Closed reduction and 2 crossed K-wires percutaneous	Plaster short leg Cast and K-wires for six weeks. After five months. The patient was able to resume all her normal activities without pain or discomfort, except for some mild swelling after activity	No data
Grambart et al. ⁽⁶⁾	2	30-year-old 67-year-old	Foot into a fence while playing softball Foot after tripping on a pothole	Proximal-medial dislocation of the first ray at the medial cuneiform-navicular joint Dislocation of the naviculocuneiform joint and fracture on the distal medial aspect of the navicular	Arthrodesis: Three 3.5-mm cortical lag screws Arthrodesis: 4.0-mm cancellous screws placed with lag technique	At the 2-w: short-leg non-weight-bearing cast At the 6-w: weight-bearing as tolerated At the 18-month had returned to his pre-injury activities, without any discomfort. Non-weight-bearing for a total of 8 w: At the 15-month, the patient reported no limitations and had a well-aligned foot	No data No data
Thompson and Cameron ⁽⁷⁾	1	21-year-old	Trauma by American football	Dislocation of the first ray at the medial naviculocuneiform joint	Open reduction and screw fixation	No data	No data
Aitken and Shortt ⁽⁸⁾	1	39-year-old	She had tripped over a domestic pet, causing her to stumble down 3 or 4 stairs	Dorsomedial dislocation of the first ray at the medial naviculocuneiform and medial intercuneiform joints	A single 2-mm. K-wire across the medial naviculocuneiform joint under fluoroscopic guidance	It was removed for 5 weeks. Progress to full weightbearing At 12 months: pain in the foot. Magnetic resonance: Nonunion of a previously unnoticed medial cuneiform fracture: Debridement, followed by autologous bone grafting and fixation with 4-mm cannulated screws. At final follow-up, 12 months following the bone grafting and internal fixation, the fusion was complete, the patient had minimal discomfort, and experienced no functional limitation	No data
Yu et al. ⁽⁹⁾	1	22-year-old	Caused by a stumble when running with the right foot in plantar flexion	Medial dislocation of the first ray at the medial naviculocuneiform and medial intercuneiform joints	Open reduction, internal fixation with K-wires	Four years after injury, the patient showed no discomfort, functional limitation, or degenerative osteoarthritis of the midfoot	No data
Schepers et al. ⁽¹⁰⁾	1	44-year-old	Fall from the stairs	Medial translation of the entire first column with a dislocation of the naviculocuneiform joint and a fracture of the medial distal part of the navicular tuberosity	Open reduction, internal fixation with plate. Non-weight-bearing for six weeks followed by a weight-bearing cast for another six weeks. Removal was scheduled: recurrent diastasis: Arthrodesis.	At 1-year follow-up She is currently walking pain-free in high heels.	No data

W: Weeks; K-wires: Kirschner wire; AOFAS midfoot score: The American Orthopaedic Foot and Ankle Society Midfoot score; VAS: Visual Analog Scale

fixation failure, secondary arthrodesis has been employed as a management option, with variable results^(8,9).

In our study, we had the opportunity to evaluate, manage, and follow two cases with the same injury affecting the medial column of the foot, but treated with different fixation methods. The choice of management was influenced by the time elapsed until initial evaluation as well as the degree of articular degeneration at the naviculocuneiform joint. In Case 1, the subtle collapse of the medial arch and early degenerative changes observed at follow-up may represent important considerations when deciding between fixation and arthrodesis in similar injuries. In contrast, Case 2 was managed with primary arthrodesis, which resulted in an adequate clinical course without complications.

Preoperative imaging studies, such as CT scans, should be performed to more clearly define key aspects of the injury, including the degree of displacement, fracture pattern, articular deterioration, and the presence of occult lesions. This information allows for more accurate preoperative planning and facilitates the selection of the most appropriate fixation method.

In this context, primary arthrodesis may be considered a potentially preferred option in patients with significant joint involvement, whereas rigid internal fixation could be reserved for cases with preserved joint structures. However, this conclusion should be interpreted with caution, as it is based on only two reported cases and limited literature. Therefore, it should be regarded as a hypothesis generating suggestion rather than a definitive treatment algorithm.

The main limitation of our study is that it includes only two cases, each managed with different surgical methods according to their specific characteristics, which influenced the choice of treatment. In addition, advanced imaging such as a CT scan was not performed preoperatively, and the follow-up period was limited to 12 months.

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Authors' contributions: Each author contributed individually and significantly to the development of this article. JMRA * (<https://orcid.org/0000-0002-9390-9496>) Performed the surgeries, data collection, survey of the medical records, and performed the clinical examination and performed the bibliographic review; RMR * (<https://orcid.org/0009-0008-7214-8262>). Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, performed the surgeries, data collection, performed the bibliographic review, formatting of the article, survey of the medical records, and performed the clinical examination. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) .

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Case Report

Simultaneous Shepherd, Cedell, and lateral process talar fractures: A case report

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Abstract

Synchronous fractures of the lateral tubercle (Shepherd), the medial tubercle (Cedell), and the lateral process of the talus, associated with a hallux fracture-dislocation, represent a rare and complex injury pattern. Few cases have been reported in the literature. We present the case of a 40-year-old male patient involved in a motorcycle accident who sustained blunt trauma to his left ankle. Initial plain radiographs and subsequent computed tomography (CT) confirmed displaced fractures involving both tubercles of the posterior process of the talus as well as the lateral process, along with a fracture-dislocation extending into the tibial condyle of the proximal phalanx at the hallux interphalangeal joint. Surgical fixation was performed, including anatomical reduction and internal fixation. Clinical and radiological follow-up over 18 months demonstrated satisfactory functional recovery and bone union, with the patient scoring 70/100 on the American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot score, 42% on the Foot Function Index (FFI), and 4/10 on the Visual Analog Scale (VAS) for pain. For the hallux, the AOFAS hallux score was 69 points. This case underscores the clinical importance of recognizing peripheral talar fractures, which are frequently overlooked on radiographs and require CT imaging for accurate diagnosis and appropriate management.

Level of Evidence IV; Case report.

Keywords: Hallux; Talus; Diagnostic imaging; Fracture fixation, internal.

Introduction

Talus fractures are rare injuries, accounting for approximately 0.85% to 1% of all fractures. They are most frequently associated with high-energy trauma, such as falls from height or traffic accidents. Fractures of the head of the talus, the lateral process, and the posterior process are collectively referred to as peripheral talar fractures. These injuries are often overlooked on initial conventional radiographs, underscoring the importance of advanced imaging such as computed tomography (CT) for accurate diagnosis⁽¹⁾.

The posterior process of the talus consists of two tubercles – the lateral and medial – separated by a groove through which the flexor hallucis longus tendon passes. Fractures of this region were first described by Shepherd in 1882, involving the lateral tubercle, and later by Cedell in 1974, involving the posteromedial tubercle. These injuries are currently classified

as lateral tubercle fractures (Shepherd's fracture), which are more common, and medial tubercle fractures (Cedell's fracture)⁽²⁾. The simultaneous occurrence of lateral and medial tubercle fractures and the lateral process of the talus, associated with a hallux fracture, represents a rare condition (Table 1).

Simultaneous fractures of the posterior and lateral processes of the talus are rare injuries, often associated with high energy trauma. We present the case of a 40-year-old male motorcycle rider who sustained this uncommon injury pattern. This report aims to describe the diagnostic workup, surgical strategy, and 18-month outcome of this rare, combined injury.

Case presentation

A 40-year-old male patient was admitted to the emergency department following a traffic accident in which he, as a

Study performed at Hospital Alma Mater de Antioquia, Medellín. Colombia.

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Table 1. Review of cases reported in the literature

Author/Year	Age (years)	Mechanism of injury	Types of fracture	Treatment	Followup (time/scales/imaging)
Benmansour et al. (1999)	32	Fall from 3 m (dorsiflexion + pronation)	Simultaneous fracture: type I lateral nondisplaced + posteromedial	Selective ORIF (posteromedial) + neurolysis (posterior tibial nerve)	12 months. No scales. No pain, no neurological deficit. 25% decrease in subtalar mobility
An et al. (2009)	26	Traffic accident	Simultaneous fracture (lateral + posteromedial). Small posteromedial fragment (8×4×4 mm)	ORIF lateral process + resection of posteromedial fragment	3 months. AOFAS 91. No pain or limp. Progressive weightbearing
Ziran (2011)	39	Motorcycle accident	Simultaneous displaced fractures (lateral + posteromedial)	ORIF of both fractures	6 months. No functional scales. ROM: -5° dorsiflexion, 30° plantarflexion. Painfree. No imaging after 3 months
Gómez Robledo (2013)	24	Workrelated trauma	Simultaneous fracture (lateral + posteromedial) + entrapment of medial neurovascular bundle	ORIF of both + neurovascular decompression	CT at 6 months: union. Followup 16 months. No functional scales. 50% decrease in subtalar mobility. Partial sensory recovery
Zhang et al. (2025)	45	Fall from 2 m	Complex fracture: lateral + posteromedial + calcaneofibular ligament avulsion	Arthroscopy: medial tubercle ORIF (Herbert screw). No lateral fixation (comminution)	Followup 84 months. Scales: serialized VAS and AOFAS. CT at 2 years: union
Present case (2026)	40	Traffic accident: motorcycle rider collided with a vehicle	Simultaneous fracture: lateral tubercle + medial tubercle + lateral process + hallux fracture	ORIF with 2.5 mm headless cannulated compression screws	18 months. AOFAS Hindfoot 81/100; AOFAS Hallux 82; FFI 33%; VAS pain 3/10. CT: bone union. Returned to work as a motorcycle driver. Mild limitation when walking on uneven ground and a 5° loss of extension at the hallux interphalangeal joint.

ORIF: Open reduction and internal fixation; ROM: Range of motion; AOFAS: American Orthopaedic Foot and Ankle Society score; VAS: Visual Analog Scale; CT: Computed tomography; FFI: Foot Function Index.

motorcycle rider, collided with a vehicle, sustaining blunt trauma to his left foot and ankle. On initial evaluation, the patient was clinically stable, with controlled pain and moderate, nontense edema of the left ankle and foot. Examination revealed evident hallux deformity, no associated wounds, adequate mobility of the other toes, a capillary refill time of 2 seconds, and a palpable pedal pulse. Touch and discriminative sensation in the autonomous zones, particularly in the distributions of the tibial, deep peroneal, and superficial peroneal nerves, was preserved.

On admission, plain radiographs of the ankle demonstrated marked soft tissue edema and a previously undescribed finding, which we term the 'double medial and lateral peritalar contour sign' (Figure 1). Images of the foot showed a displaced fracture-dislocation of the hallux in the proximal phalanx with involvement of the interphalangeal joint (Figure 2).

Closed reduction of the hallux fracture-dislocation was performed in the emergency room, and the injury was immobilized using buddy splinting and a shortleg plaster splint for the ankle. As a key element in preoperative planning, CT scans were requested to characterize the injuries and establish the surgical plan (Figure 3). The fracture of the lateral process of the talus was classified as type IIIB, according to the modified classification by Tinner and Sommer⁽³⁾, representing an articular and metaphyseal fracture that is multifragmented but reconstructable. The fracture of the posterior process was classified as a displaced Shepherd and Cedell fracture. Thus, it was considered a

type 2d injury, that is, a fracture of the lateral process along with a fracture of the posterior talar process, according to the Wang et al.⁽⁴⁾ classification. The patient was discharged with recommendations to reduce the edema, and definitive surgery was scheduled for 10 days later.

The procedure was performed under general anesthesia, with the patient in the supine position, without the use of a tourniquet, and with prophylactic administration of intravenous antibiotics. Using a posteromedial approach between the Achilles tendon and the flexor hallucis longus, the posterior process of the talus was identified under direct visualization, with careful and continuous protection of the posterior tibial neurovascular bundle and the flexor hallucis longus tendon throughout the procedure. With the aid of an external fixator acting as a tibio-calcaneal distractor, the superior half pin was placed on the medial surface of the distal tibial metaphysis, and the inferior half pin was inserted into the calcaneus just inferior to the posterior facet. The fractures of the medial and lateral tubercles were reduced and fixed using two 2.5 mm headless cannulated compression screws.

Subsequently, through a sinus tarsi approach and with the aid of an external fixator functioning as a fibulo-calcaneal distractor, the superior half pin was placed on the lateral surface of the distal fibular metaphysis, and the inferior half pin was inserted into the posterior calcaneal tuberosity. The fracture of the lateral process of the talus was then identified and reduced, and fixation was completed with two 2.5 mm headless cannulated compression screws.

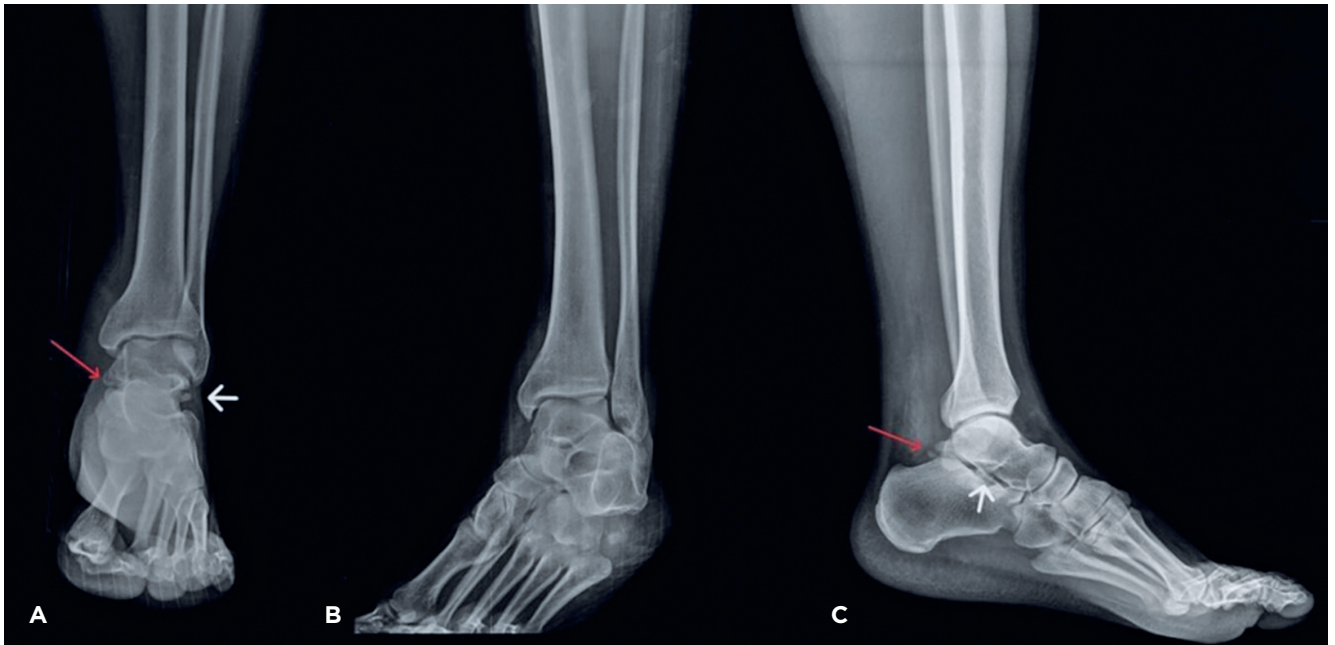


Figure 1. (A) Anteroposterior ankle radiograph. The short white arrow indicates a lateral peritalar bony double contour in the subfibular region, suggesting a fracture of the lateral process of the talus. The red arrow highlights a double contour of the medial talus, suggesting a fracture of the posteromedial process. (B) A lateral radiograph shows soft tissue swelling in the ankle. (C) A mortise radiograph; the red arrow points to the fracture line in the posterior process of the talus, and the white arrow shows the altered V-sign, which corresponds to disruption of the normal cortical outline formed by the lateral talar process and the posterior subtalar joint, and serves as an indirect indicator of fracture.



Figure 2. (A) Oblique view of the left foot, showing a fracture of the medial condyle of the proximal phalanx of the hallux, with interphalangeal subluxation (short blue arrow). (B) Anteroposterior radiograph of the foot, showing a displaced fracture of the proximal phalanx (long blue arrow).

Finally, using a dorsal approach at the level of the interphalangeal joint of the hallux, a tenotomy of the extensor hallucis longus (EHL) was performed to access the articular fracture line of the proximal phalanx. Temporary reduction was achieved with Kirschner wires; however, due to the marked instability of the hallux fracture-dislocation, definitive fixation was performed with the placement of a 1.5 mm minifragment plate. The repair of the EHL tendon was secured.

All steps were performed under fluoroscopic guidance. Extensive irrigation was performed, followed by wound closure and immobilization with a splint. The patient remained under inpatient observation for 24 hours, during which a CT scan was performed to assess the quality of the joint reduction and to rule out intraarticular implant penetration or malposition (Figure 4), and a plain radiograph of the foot was obtained (Figure 5).

The postoperative follow-up visit took place two weeks later, during which the splint and sutures were removed. Physical therapy was initiated to facilitate early rehabilitation, and immobilization with a walker boot was prescribed, along with non-weight-bearing for an additional 10 weeks. Starting in week 12, partial weight-bearing of approximately 15 kg was initiated, with a progressive and controlled increase using crutches until week 16. Subsequently, full and unrestricted weight-bearing was permitted.

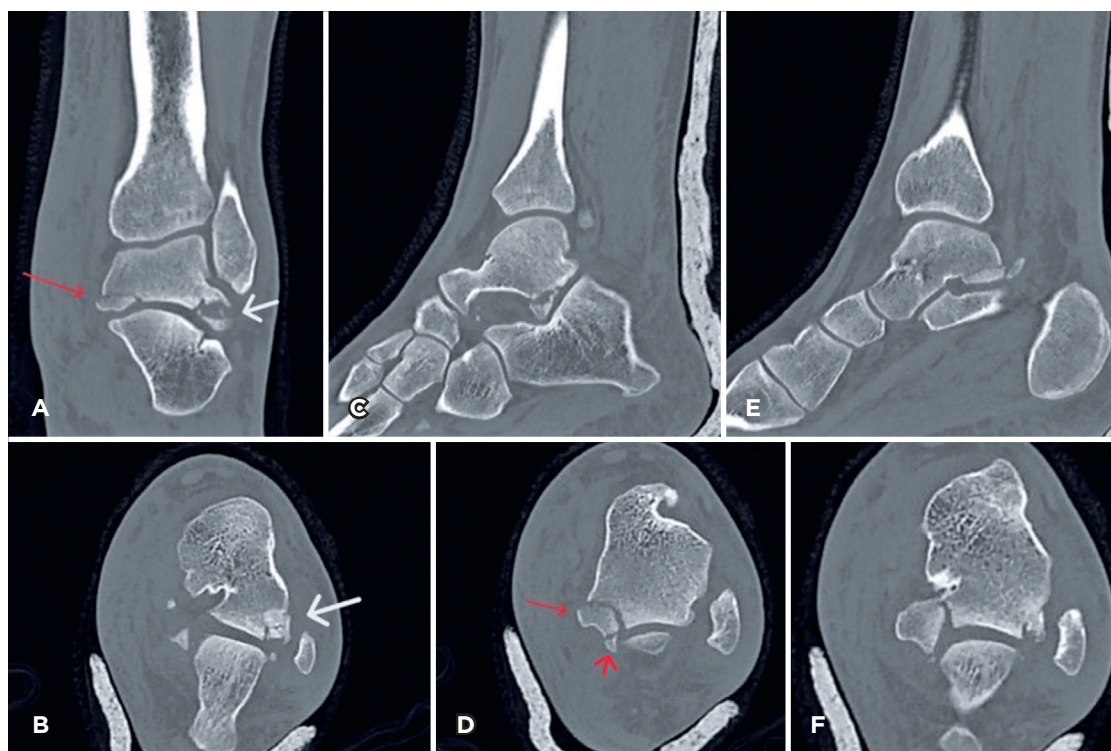


Figure 3. Preoperative computed tomography scan. (A) Coronal section showing a fracture of the lateral process (white arrow) and the posteromedial process (red arrow) (B) Axial view shows comminution of the lateral process (white arrow). (C and E) Sagittal sections demonstrate displaced fractures of the lateral and posterior processes. (D) Axial view with clearly visible Cedell's fracture (thin red arrow) and Shepherd's fracture (red arrowhead). (F) Axial view with synchronous fracture of the lateral and posterior processes.

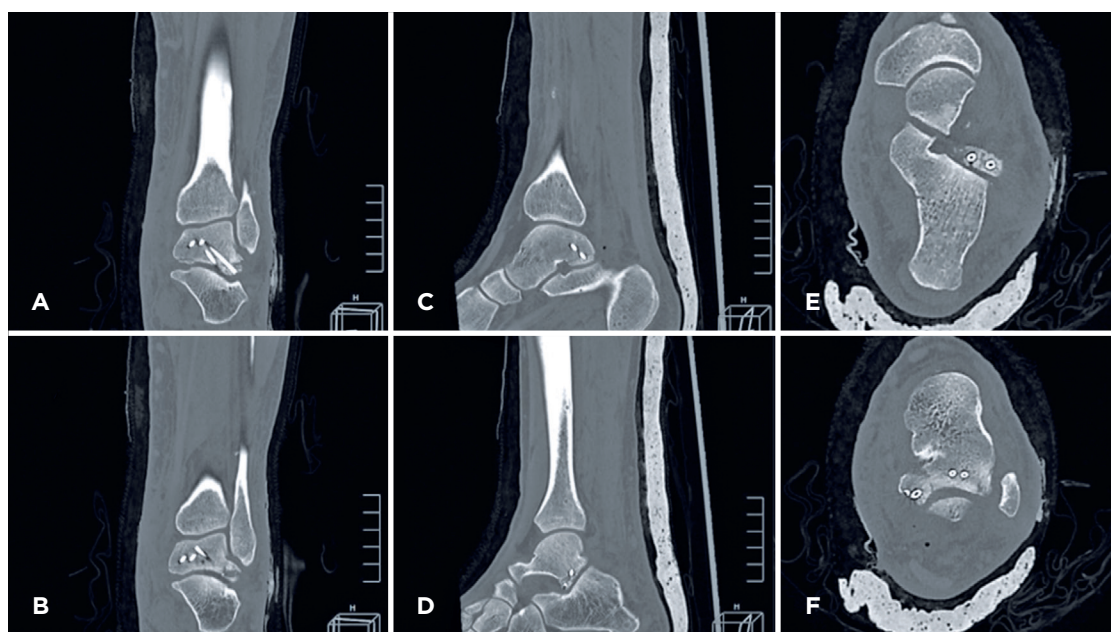


Figure 4. Postoperative computed tomography scan of the ankle obtained on the following day. (A, B) Coronal sections showing anatomical fixation of the lateral process of the talus. (C) Sagittal section demonstrating reduction with screws in the medial tubercle (Cedell). (D) Stable fixation of the lateral process. (E) Axial section showing reduction without joint stepoff and adequate fixation of the lateral process. (F) Anatomical reduction of the posterolateral tubercle of the talus (Shepherd).

In the 24-week follow-up, the patient was already bearing full weight and had adequate healing of the surgical wounds. He scored 70/100 on the American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot score, 42% on the Foot

Function Index (FFI), and 4/10 on the Visual Analog Scale (VAS) for pain. He returned to work with restrictions and began cycling as a recreational sport. At this time, a follow-up CT scan of the ankle was performed, showing complete bone union (Figure 6). Regarding the hallux, the score achieved to date on the AOFAS hallux score was 69 points.

After 18 months of follow-up, weight-bearing and comparative X-rays were performed, showing mild signs of post-traumatic subtalar osteoarthritis, with no involvement of other joints and no failure of the osteosynthesis material in the hindfoot (Figure 7). Complete union was observed in the interphalangeal joint of the hallux, with no arthritic changes (Figure 8). The patient returned to work as a motorcycle driver. He requires orthopedic footwear with a thermoformed insole providing scaphoid support to relieve residual pain. He achieved a score of 81/100 on the AOFAS hindfoot score, 33% on the FFI, and 3/10 on the VAS score for pain. Regarding the hallux, he obtained a final score of 82 points on the AOFAS hallux score (Figure 9).

Discussion

It has been reported that fractures affecting the lateral process account for 10.4% of talus fractures, with a mean patient age of 20 to 30 years, predominantly men, and a trauma mechanism resulting from motor vehicle accidents (73%)⁽²⁾. The mechanism of injury remains unclear. However, current literature suggests that forces of dorsiflexion,



Figure 5. Anteroposterior (A) and lateral (B) radiographs of the left foot, showing an adequately reduced fracture of the proximal phalanx of the hallux, without evidence of intra-articular screw/implant penetration.

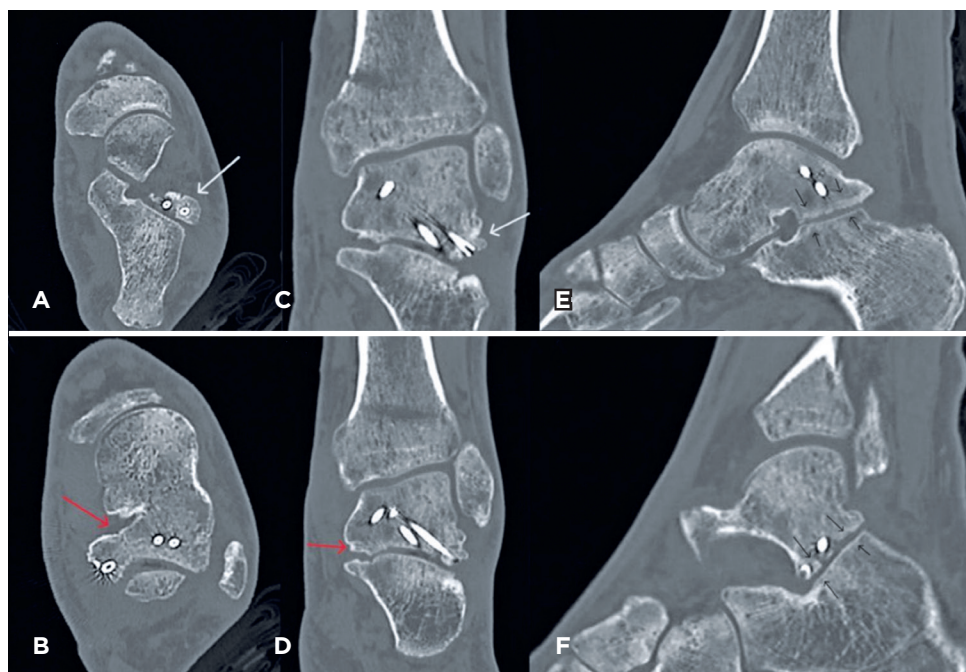


Figure 6. Computed tomography scan at week 24. (A and B) Axial view showing screws in the lateral process, non-articular (white arrow), and bone bridge (union) in the fracture of the posterior process (red arrow). (C and D) Coronal view showing bone bridge (union) in the fracture of the lateral process (white arrow), and in the medial tubercle (Cedell) of the posterior process (red arrow). (E and F) Sagittal views showing minimal changes due to subtalar osteoarthritis (short black arrows).



Figure 7. Comparative radiography at 18 months after the definitive surgery. (A) Lateral view of the ankle, showing stable fixation and minimal arthritic changes in the subtalar joint. (B) Anteroposterior view of the ankle demonstrates proper alignment of the hindfoot, without signs of avascular necrosis. (C and D) Weight-bearing views of the foot, showing proper sagittal alignment of the midfoot and forefoot.



Figure 8. Weight-bearing and comparative radiographs of the feet showing a completely healed fracture of the proximal phalanx of the hallux, proper alignment, the hallux interphalangeal joint remained congruent, and no signs of osteoarthritis in the interphalangeal joint.

inversion, eversion, and potentially external rotation are all contributing factors⁽⁴⁾. Fractures affecting the posterior process of the talus occur due to direct compression, either during dorsiflexion and pronation or during forced plantar flexion, resulting in compression of the posterior process between the posterior tibial rim and the calcaneus. They can occur in falls from height, traffic accidents, and dance, where plantar flexion is common⁽⁵⁾.

The simultaneous occurrence of fractures involving the lateral process, the lateral tubercle (Shepherd), and the medial tubercle (Cedell) of the posterior process of the talus is exceptionally rare and has been reported only in a few case reports⁽⁶⁻¹⁰⁾.

Compared with previously reported cases⁽⁶⁻¹⁰⁾, our patient shared the high-energy trauma mechanisms described, particularly traffic accidents and falls from height. In this context, our case aligns with more contemporary reports by Ziran⁽⁸⁾, Gómez Robledo⁽⁹⁾, and Zhang et al.⁽¹⁰⁾, in which anatomical reduction and internal fixation were emphasized to optimize joint congruency and reduce the risk of functional sequelae. However, unlike several of these reports, where less stable techniques or combinations of fixation and resection were employed, in our case stabilization of all fractures was achieved using rigid fixation systems with compression screws, thereby promoting a more stable biomechanical environment for bone union.



Figure 9. Comparative clinical images after 18 months of follow-up. (A) Posterior view showing adequate hindfoot alignment. (B) Anterior view showing the midfoot and forefoot without secondary deformity. (C and D) Standing on heels and toes. Note mild limitation of full extension of the left hallux. (E) The scar has healed, the midfoot arch is preserved, and there is no hallux flexus deformity.

From the perspective of the injury pattern, most of the described cases correspond to synchronous fractures of the lateral process and the posteromedial tubercle, with or without displacement. Our case presents a particularly unusual configuration – combining displaced fractures of both components (Shepherd and Cedell) of the posterior process along with a fracture of the lateral process of the talus and a hallux fracture-dislocation, which broadens the spectrum described to date in the literature. In comparison, some authors have reported associated neurovascular compromise Gómez Robledo⁽⁹⁾ or complex ligamentous injuries Zhang et al.⁽¹⁰⁾. The coexistence with a hallux injury highlights the high-energy nature of the trauma and, we hypothesize, may suggest a more aggressive combined rotational mechanism. Additionally, our approach included comprehensive imaging characterization via radiography and CT both preoperatively and during immediate postoperative followup, which allowed for precise planning and objective verification of joint reduction – an aspect not systematically documented in most published cases.

This report has several limitations. First, it describes a single case, which restricts the generalizability of the findings. Second, preinjury functional scores were not available, li-

miting the ability to quantify recovery. Third, the followup period was insufficient to fully assess the development of posttraumatic arthritis. Finally, the absence of comparative evidence prevents definitive conclusions regarding the superiority of the chosen treatment strategy.

Conclusion

This case broadens the clinical spectrum of peripheral talus fractures by documenting an exceptional synchronous combination that suggests a high-energy rotational injury mechanism more complex than is typically described. Beyond its rarity, the main contribution lies in emphasizing that the discrepancy between clinical findings and initial imaging should prompt further evaluation, as underestimation of these injuries leads to inappropriate therapeutic decisions and potential functional impairment. In this regard, the systematic integration of CT scanning into the diagnostic algorithm should not be considered complementary but rather decisive when peritalar involvement is suspected. Likewise, postoperative followup with CT scanning is essential to adequately assess the quality of reduction and to detect early posttraumatic osteoarthritic changes.

Authors' contributions: Each author contributed individually and significantly to the development of this article: JMRA * (<https://orcid.org/0000-0002-9390-9496>). Performed the surgeries, data collection, survey of the medical records, performed the clinical examination, and participated in the review process; AHD * (<https://orcid.org/0009-0008-7214-8262>) and EVP * (<https://orcid.org/0009-0006-1075-5978>) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, performed the surgeries, data collection, performed the bibliographic review, formatting of the article, survey of the medical records, and performed the clinical examination. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) 

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Case Report

Angioleiomyoma of the ankle with adjacent superficial peroneal nerve neuritis: A case report

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Abstract

Angioleiomyoma is a rare, benign soft tissue neoplasm accounting for approximately 0.2% of all tumors of the foot and ankle. It occurs most frequently in women, with a mean age at presentation of approximately 47 years. Angioleiomyoma arises from smooth muscle proliferation within the tunica media of vessels, possibly originating from arteriovenous anastomoses, and forms a well-circumscribed vascular smooth muscle tumor. Complete surgical excision is considered curative in most cases and is associated with a low reported recurrence rate. Approximately 1% of cases transform into malignant variants, including leiomyosarcoma. Early identification and appropriate management are therefore essential to optimize outcomes and mitigate the potential risk of malignant progression. We present a rare case of angioleiomyoma arising over the superficial peroneal nerve at the ankle, highlighting its clinical presentation, imaging characteristics, surgical management, and histopathologic findings.

Level of Evidence IV, Case Report.

Keywords: Angioleiomyoma; Skin neoplasms; Mass; Soft tissue neoplasms; Foot.

Introduction

Angioleiomyoma is a rare, benign soft tissue neoplasm accounting for approximately 0.2% of all tumors of the foot and ankle⁽¹⁾. It occurs most frequently in women, with a mean age at presentation of approximately 47 years⁽²⁾. Angioleiomyoma arises from smooth muscle proliferation within the tunica media of vessels, possibly originating from arteriovenous anastomoses, and forms a well-circumscribed vascular smooth muscle tumor.

Clinically, angioleiomyoma most commonly presents as a small, slow-growing, painful subcutaneous nodule in the lower extremity. Because of its nonspecific presentation and overlapping features with other neural or vascular tumors, preoperative diagnosis remains challenging and is rarely established. Definitive diagnosis is typically achieved through histopathologic examination following surgical excision.

Complete surgical excision is considered curative in most cases and is associated with a low reported recurrence rate. Approximately 1% of cases transform into malignant variants,

including leiomyosarcoma^(3,4). Early identification and appropriate management are therefore essential to optimize outcomes and mitigate the potential risk of malignant progression. We present a rare case of angioleiomyoma arising over the superficial peroneal nerve at the ankle, which is unusual in this location. We also highlight its clinical presentation, imaging characteristics, and surgical management.

Case report

A 62-year-old woman with a 2-year history of superficial peroneal nerve (SPN) neuritis and an overlying soft tissue mass presented to the podiatry clinic. The patient reported that the mass was not painful, but she had an intermittent localized burning sensation; the mass also fluctuated in size. The patient denied radiating pain from the mass; however, Tinel's test did not elicit distal radiation into the foot. Several years earlier, she had fractured her left ankle, which was successfully treated conservatively. Conservative

Study performed at the NYU Langone Health, New York, USA.

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treatments attempted for the left ankle mass included supportive footwear, ankle stretching, icing, nonsteroidal anti-inflammatory drugs (NSAIDs), compression, and local manual massage. After local manual massage, she developed worsening pain radiating to the dorsum of the foot, with associated burning and numbness (Figure 1). Clinically, the mass appeared to be approximately 5 cm proximal and lateral to the lateral malleolus. Non-contrast magnetic resonance imaging (MRI) of the left ankle showed a nonspecific, solid 5 mm nodule anterior to the lateral fibula with slight T2 hyperintensity and T1 hypointensity. The nodule appeared

to be approximately 1 cm lateral to the superficial peroneal nerve. On T2-weighted images, hypointense bands were noted, representing the “reticular sign” (Figure 2). Additional findings included a medial talar dome osteochondral defect (OCD) measuring 7 x 7 mm, mild anterior and posterior tibial tenosynovitis, mild peroneal tendinosis, and scar remodeling of the anterior talofibular ligament (ATFL). At that time, the patient had exhausted conservative treatment and continued to experience worsening pain in the lateral left ankle; therefore, the team decided to proceed with operative treatment of the left ankle soft tissue mass.



Figure 1. Unremarkable left ankle radiograph.

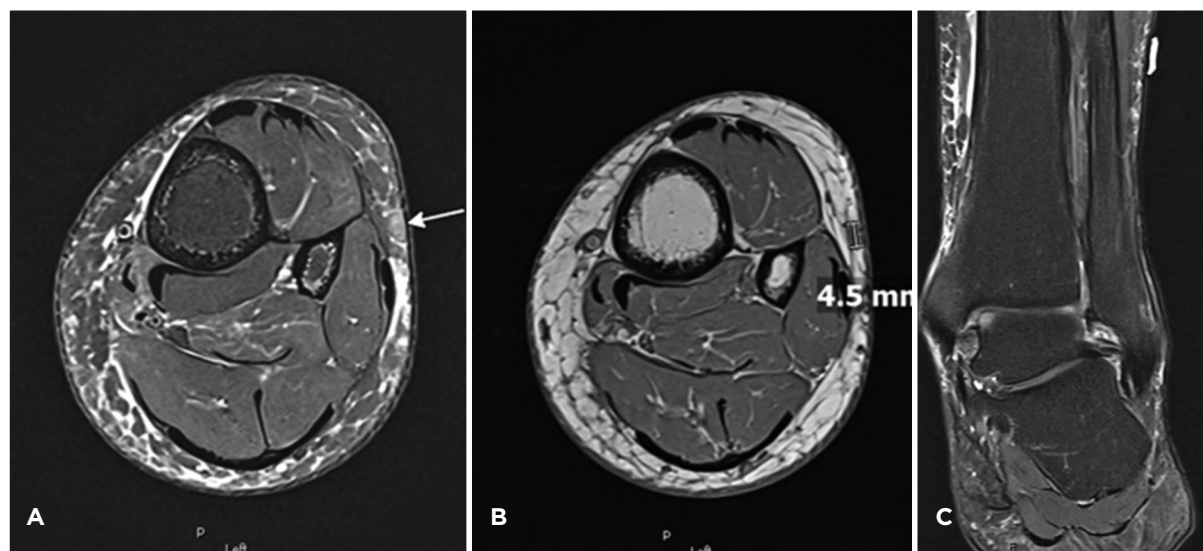


Figure 2. Angioleiomyoma finding. (A) Axial T2-weighted magnetic resonance imaging. (B) Axial T1-weighted magnetic resonance imaging. (C) Coronal T2-weighted fat-saturated magnetic resonance imaging.

The patient was evaluated at two and six weeks postoperatively. At the first postoperative visit, she rated her pain as 0 out of 10 on the visual analog scale (VAS). She reported some tenderness at the surgical site during weight-bearing, which improved with icing, ambulation in a surgical shoe, and use of a knee scooter. The sutures were removed, steri-strips were applied, and the patient was advised to return to normal footwear with a gradual return to activity. At the 6-week follow-up visit, she again rated her pain as 0 out of 10 on the VAS scale and reported complete resolution of the preoperative neuritis. She was advised to return to full activity along with physical therapy and home exercises. She was also encouraged to continue with manual scar tissue manipulation along with nerve flossing techniques to minimize recurrent irritation of the superficial peroneal nerve.

Operative procedure

A 2cm linear longitudinal incision was made directly over the palpable soft tissue mass on the lateral aspect of the left ankle and extended to the subcutaneous tissue. Careful dissection was performed through the subcutaneous tissue, and the superficial peroneal nerve was identified and retracted. A firm soft tissue mass with well-defined boundaries was identified and carefully resected using a Metzenbaum scissors. The mass was completely resected and was notably paler than the surrounding subcutaneous tissue. The mass measured 5 x 5 mm and was sent to pathology for further examination (Figure 3). The surgical site was examined, and no residual soft tissue mass was observed. A postoperative injection consisting of 2 mL of dexamethasone at 4mg/mL was administered locally to the surgical site before application of the postoperative dressing.

Discussion

Angioleiomyoma accounts for 70%-80% of mesenchymal tumors and 4.4%-5% of benign soft tissue tumors⁽³⁾. Angioleiomyoma are classified into three subtypes: solid, venous, and cavernous⁽¹⁾. Solid tumors are defined by smooth muscle cells surrounded by poorly defined capillaries⁽⁵⁾. Venous tumors are characterized by thicker muscular channels⁽⁵⁾. The cavernous subtype, the least common, has dilated vascular channels with small muscular layers⁽⁵⁾. Malignant transformation is rare, accounting for 1% of reported cases⁽¹⁾. However, treatment is important when patients become symptomatic. In the present case, the mass was 1 mm lateral to the SPN, causing neuritis and adjacent nerve impingement. Pain is one of the symptoms associated with these tumors. Compression of interstitial nerves combined with ischemia appears to cause the pain⁽⁶⁾.

In the differential diagnosis, it is important to distinguish angioleiomyoma from other soft tissue tumors. Schwannomas are peripheral nerve tumors that are eccentrically located and may appear clinically similar to angioleiomyoma. Histopathologically, schwannomas show spindle-shaped cells in a palisading pattern⁽⁷⁾. Glomus tumors are mainly located in the subungual region and have arteriovenous anastomoses, an atypical finding for the soft tissue mass in the present case⁽⁸⁾. Hemangiomas are uncommon in the extremities and are mostly found in the head and neck⁽⁹⁾. They are relatively benign lesions with a dark red appearance.

A case series reviewed MRI findings of angioleiomyoma. These benign tumors demonstrate high intensity on T2-weighted imaging; however, they show a dark reticular sign at the peripheral rim⁽¹⁰⁾. This sign represents interlacing

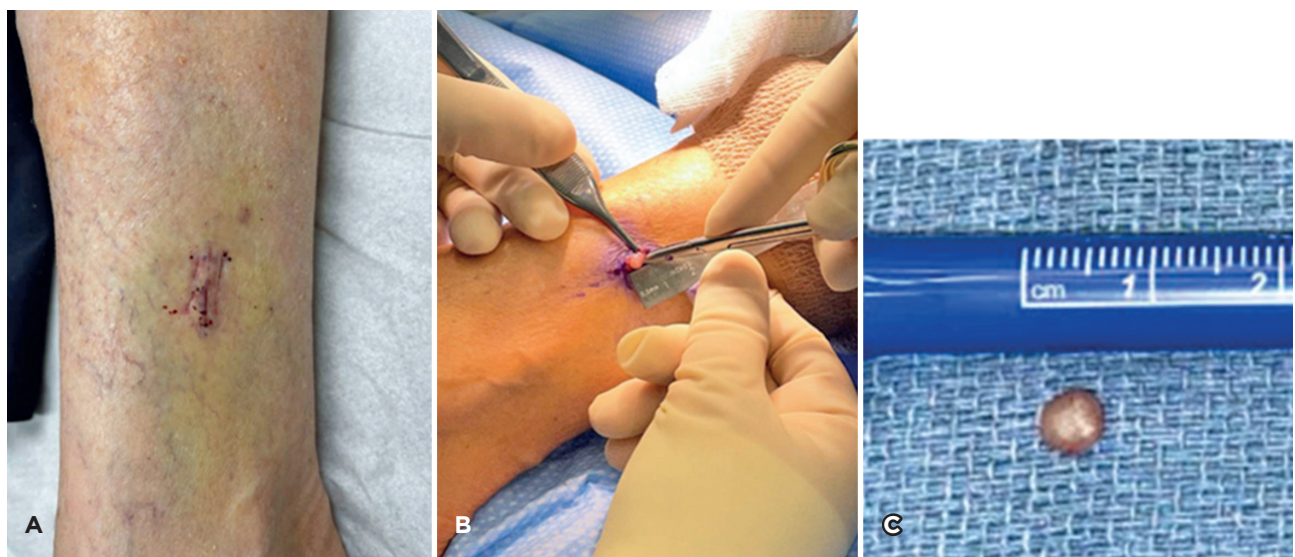


Figure 3. (A) Postoperative incision. (B) Intraoperative finding of mass. (C) Measurement of the mass.

septa and has high interrater reliability for identifying angioleiomyoma. Our patient's MRI showed a slightly hyperintense T2-weighted signal with a peripheral rim when compared with the vitamin E marker. However, establishing a definitive diagnosis of angioleiomyoma based on MRI alone remains challenging.

Surgical excision of such tumors is considered the gold standard^(1,5), with a recurrence rate of 2.8% after two years⁽¹⁾. Malignancy is a concern, with a 5-year survival rate of 20%-35%⁽¹⁾. However, given the pain associated with these lesions, the time to surgery may be shorter, potentially reducing the likelihood of malignancy.

Authors' contributions: Each author contributed individually and significantly to the development of this article: EJ *(<https://orcid.org/0009-0001-4783-7137>) Conceived and planned the activities that led to the study; BS *(<https://orcid.org/0009-0004-0433-8524>) and CA *(<https://orcid.org/0000-0002-3633-7532>) Interpreted the results of the study and participated in the review process; LJ *(<https://orcid.org/0000-0002-0932-6053>) Performed the surgeries and data collection. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) .

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Letter to the Editor

Commentary on: “A comparison of foot pain and dynamic stability among flat and heeled footwear users in undergraduate female medical students”

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We read with great interest the article “Comparing foot pain and dynamic stability among flat and heeled footwear users in undergraduate female medical students.” This study addresses an often-overlooked health issue: the long-term musculoskeletal consequences of habitual footwear choices among young professionals. The topic is clinically relevant, particularly in populations where prolonged use of heeled footwear is common. The authors should be commended for addressing an understudied population and for employing validated outcome measures such as the visual analog scale and the Four Square Step Test (FSST)⁽¹⁾.

The study demonstrates several methodological strengths, including a clearly defined objective, an adequate sample size, appropriate differentiation of heel-height categories, and the use of suitable statistical tests after assessing data normality. Reporting test-retest reliability for the FSST and acknowledging study limitations further enhance the study's transparency.

However, certain methodological and interpretative aspects need discussion. First, the use of a convenience sampling technique from a single academic institution limits external validity. While this is acknowledged by the authors, the conclusions appear to extend beyond what the sampling frame reasonably supports. The findings may not be generalizable to non-medical students, working women, or older populations, in whom footwear habits, physical activity levels, and musculoskeletal loading differ substantially.

Second, while the use of ANOVA and Kruskal-Wallis tests is appropriate, the analysis relies predominantly on p-values. Reporting effect sizes and confidence intervals would have provided a clearer understanding of the clinical relevance of the observed differences, particularly given the statistically significant findings across heel-height categories⁽²⁾.

Additionally, the absence of multivariable analyses limits the ability to examine variables such as body mass index, duration and frequency of heel use, habitual physical activity, and previous minor foot symptoms that did not meet the exclusion criteria.

Third, the categorization of heel height also deserves consideration. Grouping a wide range of heel heights into broad categories may introduce misclassification bias and obscure dose-response relationships. Future studies might benefit from narrower heel-height intervals or from analyzing heel height as a continuous variable.

In conclusion, present a timely and clinically meaningful study. Addressing the above points in future research through longitudinal designs, probabilistic sampling, and multivariable statistical approaches would further strengthen the evidence base and enhance the applicability of the findings.

We congratulate the authors on their contribution and appreciate the opportunity to engage in this scholarly discussion.

Study performed at the Markandeshwar (Deemed to be University), Mullana, Ambala, Haryana, India.

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Note: The Editor-in-Chief wishes to inform readers that the authors of the original article were duly notified of the submission of this commentary concerning their work. In keeping with the Journal of the Foot & Ankle's commitment to editorial fairness and the principles of scientific dialogue, the authors were invited to submit a written response, which would have been published concurrently with this commentary. No response was received within the time period established by the Journal.



Authors' contributions: Each author contributed individually and significantly to the development of this article: KC*(<https://orcid.org/0009-0002-0948-8981>) Wrote the article; PS *(<https://orcid.org/0000-0002-8593-7825>) Formatting of the article. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) .

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O **Journal of the Foot and Ankle** adota um fluxo de avaliação e revisão das submissões que demanda alguns passos e tempos que devem ser respeitados não sendo passíveis de supressão ou aceleração. Por isso, é muito importante submeter os trabalhos ao JFA o quanto antes para evitar atropelos relativos aos prazos de concursos e exames.



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Caio Nery

Editor-Chefe

Journal of the Foot and Ankle