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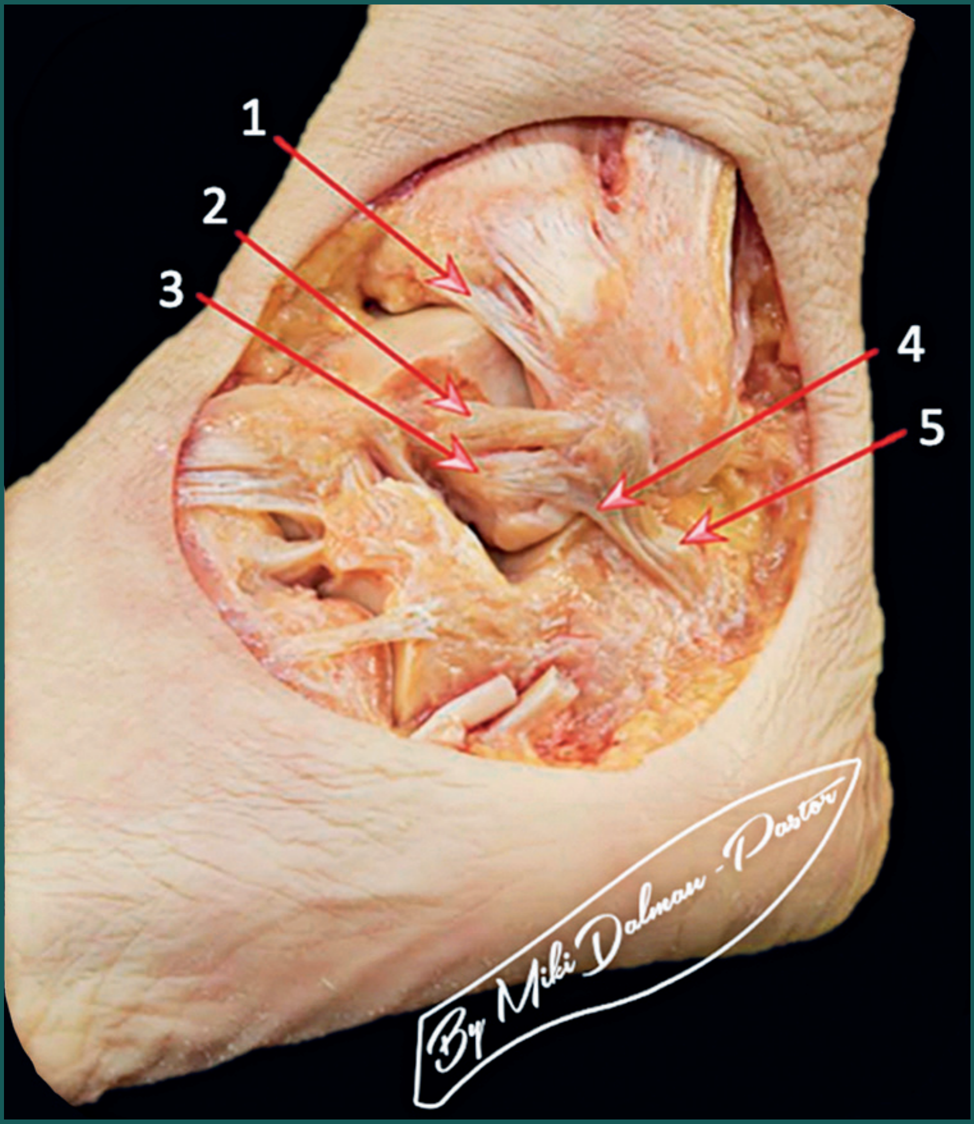

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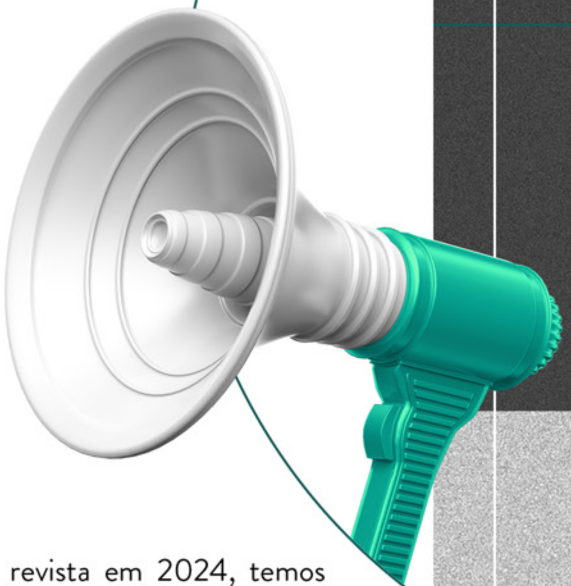

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Prezado Coordenador,

Com a publicação deste segundo número de nossa revista em 2024, temos apenas mais uma oportunidade neste ano para que os serviços cumpram a determinação da **CET-ABTPé** para a manutenção de seu credenciamento:

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Caio Nery
Editor-Chefe
Journal of the Foot and Ankle

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Volume 18, Issue 2, May-August

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Editorial

JOURNAL OF THE Foot & Ankle JFA

ANTÔNIO ALÍCIO MOREIRA DE OLIVEIRA JÚNIOR

PRESIDENTE DO 21º CONGRESSO BRASILEIRO DE CIRURGIA DO TORNOZELO E PÉ

ABTPé: A Testament of Growth and Excellence in Foot and Ankle Surgery

Our growth is undeniable! The evolution of the Brazilian Association of Medicine and Surgery of the Ankle and Foot (ABTPé) over the past few years is a testament to this. We have revamped the criteria for resident training, regulated, valued, and qualified training services, embraced the digital era, and made continuing education accessible online. The addition of thematic courses in the annual continuing education calendar has enriched our events, providing a platform to delve into the nuances that set specialists apart. We have also been fortunate to benefit from the expertise of our members, including Nicola Maffulli, Jonathan Deland, Tim Schepers, and others, who have shared their unique perspectives and experiences with us.

With all these advances, we have also seen the growth of our publications in the best journals in the specialty, the development of new surgical techniques, the creation of international partnerships with colleagues of great relevance, and what began as a club in the pioneering days of foot and ankle surgery has evolved into a dynamic, ever-evolving society, with multiple leaders and reference services spread throughout the country.

We cannot overlook the Brazilian Congress of Foot and Ankle Surgery as a significant chapter in our society's evolution. This robust event draws massive participation from our specialists and esteemed international guests, showcasing diverse perspectives. Our strong partnership with the industry also plays a crucial role, as symposia and exhibition stands introduce new solutions, trends, and designs of fixation devices.

Building this new space for publications and disseminating the experience of foot and ankle surgery in Latin America and worldwide was a courageous decision by the ABTPé, supported by the efforts of those who voluntarily dedicated themselves to editing, selecting, and disseminating the submitted papers. The authors publish more relevant information with each edition, translated into original articles, technical tips, and reviews. Yes, we are capable, and our efforts have put us on a path of success and growth that is irreversible.

Our commitment to high-level foot and ankle surgery is unwavering and is evident at every meeting, course, and congress. Our journal, a reflection of this dedication, is no exception. It serves as a testament to our growth and competence in the field.

Enjoy ABTPé; enjoy our Journal of Foot and Ankle.

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Special Article

Lateral ankle instability

Gustavo Araujo Nunes[1,2], **Tania Szejnfeld Mann**[3], **Matteo Guelfi**[2,4], **Miki Dalmau-Pastor**[2,5], **Guillaume Cordier**[2,6], **Jordi Vega**[2,5]

1. Foot and Ankle Unit, COTE Brasília Clinic, Brasília, DF, Brazil.
2. Grecmip MIFAS (Group of Research and Study in Minimally Invasive Surgery of the Foot – Minimally Invasive Foot and Ankle Society).
3. Escola Paulista de Medicina - UNIFESP, São Paulo, SP, Brazil.
4. Foot and Ankle Unit, Clinica Montallegro, Genoa, Italy.
5. Human Anatomy and Embryology Unit, Department of Pathology and Experimental Therapeutics, School of Medicine and Health Sciences. University of Barcelona, Barcelona, Spain.
6. Sport Surgery-Foot and Ankle- Clinique du Sport, Bordeaux Merignac, France.

Abstract

Ankle sprains are frequent injuries among athletes and the general population, making them one of the most prevalent sports-related injuries. While most lateral ankle ligament injuries typically respond well to conservative treatment, a significant portion evolves into chronic lateral ankle instability, which may require surgical intervention. Recently, new anatomical insights regarding the lateral ankle ligaments have emerged, enhancing the advancement of innovative diagnostic and treatment approaches. The objective of this article was to discuss the latest trends in lateral ankle instability.

Level of evidence V; Expert opinion.

Keywords: Ankle arthroscopy; Ankle instability; Ligament repair; All-inside repair.

Introduction

Ankle sprains with lateral ankle ligament (LAL) injuries are among the most common causes of orthopedic consultations. They account for around 25% of all musculoskeletal system injuries, affecting general and young patients engaged in physical activities[1]. Most (80%) LAL injuries involve the anterior talofibular ligament (ATFL), with the remaining cases resulting from combined damage to the ATFL and calcaneofibular ligament (CFL)[1,2].

Beyond the impact on the individual's quality of life, ankle sprains with LAL can develop a high recurrence rate and chronic ankle instability (CAI), which has long-term consequences that may impact patient outcomes[3,4]. It is estimated that approximately 40 % of the patients will suffer at least one more ankle sprain following an acute lateral ankle sprain at one year. After a new ankle sprain beyond the ligament reinjury, there is an increased risk of associated injuries such as an ankle fracture, cartilage injury of the talus, or syndesmotic injuries[3,5].

Due to the importance of this pathology, several anatomical and biomechanical studies on the lateral ligaments have been conducted in recent years. These studies have provided a better understanding of this pathology and the evolution of new methods of diagnosis and treatment[6-9]. The purpose of this article is to review the current trends in the anatomy, diagnosis, and treatment of patients with lateral ankle instability.

Anatomy

The ankle's lateral ligament complex consists of the ATFL superior fascicle (ATFLsup), the ATFL inferior fascicle (ATFLinf), the CFL, and the posterior talofibular ligament (PTFL). These ligaments are crucial for the ankle joint's lateral stability, maintaining stability by limiting the talus's anterior translation and internal rotation[1].

The ATFL is the primary restraint for anterior talar translation and is often injured in lateral ankle sprains. It typically consists of two bundles (superior and inferior) divided by a gap that

Study performed at the Foot and Ankle Unit, COTE Brasilia Clinic, Distrito Federal, Brazil.

Correspondence: Gustavo Araujo Nunes. SGAS 915 Lote 68a Salas 16/17 Centro Clínico Advance 2 - Asa Sul, 70390-150, Brasília, DF, Brazil. **Email:** gustavoanunes@hotmail.com **Conflicts of interest:** none. **Source of funding:** none. **Date received:** August 17, 2024. **Date accepted:** August 18, 2024. **Online:** August 30, 2024.

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permits vascular branches to enter from the perforating peroneal artery, which connects with the lateral malleolar artery[10].

The ATFLsup is an intraarticular structure with a fibular insertion placed under the distal insertion of the anterior inferior tibiofibular ligament (AITFL). The ATFLsup runs anteriorly and horizontally to be inserted on the talar neck, close to the talar dome's articular surface. It becomes lax in ankle dorsal flexion and taut in plantar flexion[7].

The ATFLinf is an extraarticular structure with a common fibular origin at the inferior tip of the fibula with CFL. From the fibular origin, the ATFLinf runs anteriorly, parallel to the ATFLsup, to attach to the talar neck just below the talar insertion of ATFLsup. Furthermore, the ATFLinf and the CFL are connected through arciform fibers and were observed as isometric structures. Considering these anatomical correlations, the ATFLinf, CFL, and their connections are described as a single functional anatomical structure named the lateral fibulotalocalcaneal ligament complex (LFTCL)[6,7]. A biomechanical study has shown the connecting fibers between the ATFLinf and CFL are robust enough to transmit tension between both structures[11].

The CFL has a distinct function because it is the only ligament connecting the talocrural and subtalar joints. It is a cordlike or flat and fanning band extraarticular structure, and most of the ligament is covered by the peroneal tendons sheath. This ligament has a common fibular origin with the ATFLinf. It runs in a posterior-inferior direction under the peroneal tendons sheath to insert into the small tubercle at the posterior aspect of the lateral calcaneus surface[12-14]. The CFL is a critical stabilizer of the lateral ankle, contributing significantly to ankle stability by preventing excessive inversion and providing resistance to the talar tilt. The insertion of the CFL on the calcaneus is approximately 13 mm from the subtalar joint[6,12,13,15].

The PTFL is the strongest ligament of the LAL. This ligament demonstrates different states of tension during ankle movements, being relaxed during plantar flexion and tensioned during dorsiflexion. Anatomically, the PTFL is a multifascicular ligament originating from the lateral malleolus's malleolar fossa on the medial surface. It runs nearly horizontally to insert in the posterolateral aspect of the talus[10,16]. An anatomical study with a tridimensional analysis of the LAL showed that the ATFLif, CFL, and PTFL have a continuous fibular footprint at the medial side of the fibula. Considering this data, the PTFL was suggested as part of the LFTCL[7,17] (Figure 1).

Concepts

Chronic ankle instability is traditionally defined as recurrent ankle sprain in patients with objective instability. This laxity can be clinically demonstrated in specific clinical maneuvers[3,18]. Individuals with this condition often suffer from significant instability accompanied by functional limitations, decreased levels of activity, and recurrent instances of ankle sprains, which can eventually result in the onset of ankle osteoarthritis[19].

According to the modern anatomical description of the LAL, depending on the ligament affected, the patient can develop ankle micro- or macro-instability[19].

Ankle micro-instability is characterized by subtle or minor ankle joint instability caused by an inversion ankle sprain with an isolated ATFLsup injury. Patients with this condition usually report a subjective sensation of the ankle giving way associated or not with pain in the lateral gutter. This type of instability is distinct from gross clinical laxity and major ligamentous disruptions. Since the injury occurs only of ATFLsup and the LFTC is intact, the lateral ankle instability is subtle and may not be demonstrated by the classical objective clinical and radiological examinations[19,20].

Before the anatomical understanding of the lateral ligament complex, this condition was either neglected or treated only as an anterolateral soft tissue impingement. The physiopathology of ankle micro-instability is understood as the knee's anterior cruciate ligament (ACL) injuries. In the same way as the ACL, the ATFLsup cannot heal after an injury because they are an intraarticular structure. Synovial fluid prevents collagen synthesis, thus explaining why intraarticular ligaments do not heal adequately[19].

Figure 1. Anatomic dissection showing the lateral ankle ligaments: (1) Anterior inferior tibiofibular; (2) Anterior talofibular superior fascicle; (3) Anterior talofibular inferior fascicle; (4) Arciform connecting fibers; (5) Calcaneofibular.

Micro-instability may be a key factor in developing associated intraarticular injuries, emphasizing the need to address subtle ligamentous issues to prevent further joint degeneration. With an ATFLsup injury, the talus biomechanic changes work with increased internal rotation. Consequently, associated deltoid injuries can occur, developing rotational ankle instability. The natural progression occurs with chondral and osteochondral injuries, anterior tibia osteophytes, and finally, ankle arthrosis[20,21].

Diagnosis

Clinical exam

The clinical exam typically involves a comprehensive review of the patient's history, symptoms, functional limitations, and physical findings related to the ankle joint[22,23]. Patients commonly experience sensations of the ankle "giving way," frequent sprains, persistent ankle pain, swelling, episodes of locking, mechanical symptoms, and restricted range of motion (ROM)[18].

It is essential to examine both ankles for comparison during the physical exam. Significant variations of joint laxity exist among individuals, depending on genetics, age, and gender. The traditional and specific tests for lateral ankle instability include the anterior drawer test and the talar tilt test. To ensure reliable results, it is essential to position the patient correctly, allowing the gastrocnemius complex to relax. Incorporating an internal rotation force during the anterior drawer test enhances the test's specificity by minimizing the effects of the deltoid ligament on the interpretation of results[24].

A novel maneuver, known as the tibiotalar posterior drawer test, has been developed to evaluate patients suspected of ankle micro-instability, mainly focusing on the tightness of the ATFLsup during plantar flexion and its role in limiting talar internal rotation. During this test, the patient lies on the examination table with a flexed hip and knee to allow full ankle plantar flexion and the foot resting on the table. By internally rotating the foot slightly and pushing the tibia posteriorly, any posterior tibia and fibula translation indicates potential injury to the ATFLsup[19].

Radiography

Radiography is crucial for evaluating associated injuries, such as impingements, syndesmosis injuries, osteochondral injuries, and ankle fractures, on the base of the fifth metatarsal, on the anterior process of the calcaneus and the lateral process of the talus. It can also detect ankle alignment and morphological changes that could contribute to instability[5].

Stress radiography to evaluate lateral ankle instability is no longer used. The subjective application of force during this procedure may not accurately reflect the necessary level of stress required to provoke instability[25].

Ultrasonography

The ultradound (US) is a valuable diagnostic tool to evaluate the LAL. Its real-time imaging capacity allows for dynamic evaluation, capturing nuances of ligament integrity and ankle stability during movement. Moreover, the US is an important tool for diagnosing micro-instability since it can identify the ATFL fascicles separately. The main disadvantage of this exam is that it is a dependent operator and requires a radiologist's expertise to interpret the findings correctly[26-28].

Magnetic resonance image

Magnetic resonance imaging (MRI) helps detect ligament injuries and associated pathologies, such as osteochondral injuries of the talus, impingements, bone bruises, occult fractures, tendon injuries, and related syndesmosis and deltoid ligament injuries, that may be present in patients with CAI[29-32].

MRI findings that indicate chronic injury to the lateral ligaments consist of heterogeneous fiber signals, irregular contours, elongation, ligament attenuation, or ligament absence. Another possibility is to analyze the ATFL fascicles. A recent study has shown that a three-dimensional volumetric MRI modality can identify the ATFL fascicles and the ligament connections, providing detailed information on their anatomy, structure, and integrity[33,34]. Therefore, the MRI can be an essential tool to diagnose micro-instability (Figures 2 and 3).

Some authors have found preoperative MRI reliable and valid for surgical decision-making in CAI. In a study involving 22 patients with CAI submitted to ankle arthroscopy following preoperative MRI, the authors determined that MRI is sensitive in identifying abnormality in the ATFL. However, the agreement between MRI findings and arthroscopic assessment was moderately substantial (k = 0.70). The study reinforces that MRI can detect intrinsic ligament defects or deficiencies but cannot evaluate ligament function[35]. One of the primary limitations of MRI is that it is typically conducted

Figure 2. Tridimensional volumetric sagittal magnetic resonance image showing the anterior talofibular ligament (ATFL) fascicles with the superior ATFL fascicle (red arrow) and inferior ATFL fascicle (blue arrow).

without physiologic weight-bearing, and although MRI-compatible stress devices exist, they have yet to be widely available. Therefore, it is crucial to correlate MRI findings with the clinical examination. Since MRI is not a dynamic exam, only morphological abnormalities can be reported, which may not always correlate with clinical findings[35].

Conservative treatment

Conservative approach should be the first line of treatment for LAL[3]. Although conservative methods cannot restore ankle stability, they are important for treating symptoms and strengthening secondary ankle stabilizers. The protocols emphasize early mobilization, functional rehabilitation, and patient education, which have been shown to enhance outcomes and reduce the risk of chronic instability post-ankle injuries.

The most modern protocol to treat acute and chronic LAL injuries is based on the acronym PEACE and LOVE[36]. The PEACE protocol focuses on the acute phase of injury management. Key components of this protocol include "P" protecting the injured area, "E" elevating the ankle to reduce swelling, "A" avoiding anti-inflammatory medications, "C" compression to manage edema, and "E" educating the patient on early intervention and proper care. The LOVE protocol becomes relevant as the acute phase transitions into the subacute and chronic stages, emphasizing Load, Optimism, Vascularization, and Exercise. Central tenets of the LOVE protocol include progressively loading the ankle for strength and stability, fostering a positive mindset through optimism, promoting vascularization for improved blood flow and tissue healing, and engaging in targeted exercises for function restoration and injury prevention[36].

Surgical treatment

Surgical treatment is indicated in cases where the conservative approach has failed. The definition and time of failure of conservative treatment in these cases have changed in recent years. The surgical indications have increased with the advancement of fully arthroscopic techniques, low morbidity, and the possibility of early rehabilitation. Several surgeons consider that if conservative treatment fails for three months, surgery may already be indicated[37,38]. The risk of persisting with conservative treatment is that repetitive ankle sprains can develop associated intra-articular injuries. The presence of these associated injuries tends to have a worse prognosis[39]. Therefore, early surgical intervention for CAI is recommended before the onset of associated injuries[38,40]. The authors of this study corroborate this approach but emphasize that treatment should always be individualized, and the peculiarities of each patient, such as comorbidities, age, level of physical activity, and associated injuries, must be considered in this decision-making.

The open Brostrom Gould surgery has traditionally been considered the gold standard for CAI treatment[41]. With the evolution of anatomical knowledge and the development of arthroscopic techniques, this scenario has changed in recent years. In addition to allowing the evaluation and treatment of injuries associated with the modern arthroscopic approach, it allows evaluating the quality of ligament remnant, performing fully anatomical all-inside ligament repair techniques, and increasing biological or synthetic reinforcements when necessary[20,42,43]. Recently, several comparative studies and meta-analyses have shown that the arthroscopic treatment of LAL has provided results that achieved similar or even superior clinical scores and faster rates of motion recovery. Additionally, it may facilitate an accelerated postoperative rehabilitation process[43,44].

Arthroscopic assessment

The ability to evaluate ligaments and related intra-articular ankle injuries has established arthroscopy as a crucial tool in managing CAI. The arthroscopic evaluation of CAI may include additional procedures, such as medial ligament repair, syndesmosis stabilization, or treatment of cartilage injuries[43].

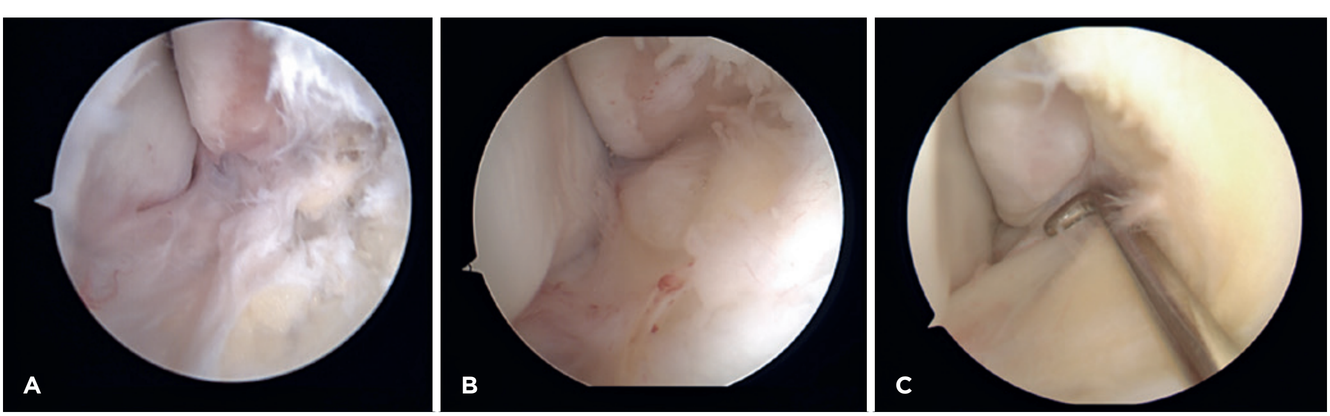

Figure 3. Arthroscopic lateral ligament quality assessment. (A) Partial ligament detachmen; (B)Total ligament detachment; (C) Hook palpation.

The management of CAI encompasses various arthroscopic treatment options, such as lateral ligament repair, repair with augmentation, and ligament reconstruction. The appropriate procedure selection depends on factors like the quality of the ligament-tissue remnant, age, hyperlaxity, body weight, sports involvement, and competition level(18). The best way to evaluate the quality of ligament remanent is during the arthroscopic intervention. It is possible to visualize and evaluate the ligament tension by hook palpation(45,46) (Figure 3). This analysis is subjective and depends on the surgeon's experience. Some surgeons proposed an arthroscopic classification of the quality of the ligament remnant tissue(45) (Table 1).

When the remaining ligament quality is moderate or poor, biological or non-biological augmentation may be necessary, particularly for patients with hyperlaxity, high body mass index (BMI), or high-level athletic demands. In cases with no native ligament remnant for repair or revision, anatomic reconstruction using a tendon graft may be necessary(18).

Arthroscopic all-inside repair

The arthroscopic all-inside repair (AIR) is a fully arthroscopic and anatomical technique described by Vega et al.(47). This procedure involves directly repairing the LAL into their footprints. This technique is indicated for patients with micro- and macro-instability with good-quality ligament remnant (9).

The literature indicates that arthroscopic AIR is an anatomical, safe, and reproducible method that can effectively repair the LAL with minimal risk to the nearby anatomical structures.(9,47) Because the suturing and reinsertion of the ligaments are conducted exclusively within the joint under direct arthroscopic visualization, the likelihood of entrapment of the superficial fibular nerve is lower compared to other arthroscopic techniques(48,49). Vega et al. presented a case series involving 24 patients with CAI who were treated through AIR of the ATFL and CFL, increasing the American Orthopaedic Foot and Ankle Society (AOFAS) scores from 65 to 97 points, with no recurrences and only one case (4.2%) of superficial peroneal nerve neurapraxia(8). Pellegrini et al. reported superficial peroneal nerve neurapraxia in 15% of patients submitted to the Artrobrostrom procedure, (41) while Acevedo et al.(42) and Corte-Real et al.(50) documented rates of 6.8% and 10.7%, respectively.

Table 1. Arthroscopic classification of the lateral ligament remnant tissue's quality

Quality	Description
Poor	Arthroscopic observation of a clearly hypoplastic ligament with poorly defined margins. The friability of the ligament makes it difficult to grasp
Moderate	Arthroscopic observation of fibrotic tissue or synovitis demonstrating a stretched hyperplastic or hypoplastic ligament. Initial good consistency of the ligament, but fragile when it is reiteratively grasped
Excellent	Arthroscopic observation of normal synovial tissue demonstrating a ligament with sharply defined margins. Solid consistency of the ligament when grasped

Despite the distrust of some surgeons in performing only a pure ligament repair, it is crucial to highlight that for effective restoration of ankle stability via a direct and isolated repair, the integrity of the remaining ligament must be sufficiently high to allow for proper grasping, tensioning, and reinsertion into its natural footprint(9). In addition to the quality of ligament remnant, this technique is anchored in new anatomical ligament concepts that demonstrate that lateral ligaments have connections and work as a ligament complex described by Vega et al. as LFTC(17). Nunes et al. reported a case series involving 18 patients with CAI who had well-preserved ligament remnants and underwent AIR of the ATFL. Based on the anatomical understanding of the relationships between the ATFL and CFL, ankle stability was restored in all cases, even when both ligaments were involved in the injuries(9).

The AIR is an anatomical procedure in which the ligaments are reinserted into the footprint. Consequently, this will generate a more physiological result with less stiffness(49). After any arthroscopic repair or reconstruction of lateral ankle ligaments, a reduction in ankle ROM is anticipated. One comparative study found that this stiffness is more pronounced in percutaneous ligament repair methods assisted by arthroscopy, as these techniques involve suturing the capsule, retinaculum, and sural fascia together, which can lead to excessive fibrosis in the lateral ankle region(49).

It is essential to consider that despite the advantages of AIR, it also has some limitations. Firstly, it is a demanding technique that requires expertise in arthroscopy. The results of this procedure are influenced by the surgeon's progress through the learning curve, making it unsuitable for novice ankle arthroscopists. Secondly, the AIR is limited to patients with good quality remnant ligament without hyperlaxity and normal BMI. Patients with long-term CAI, poor ligament remnant, generalized ligament laxity, high BMI, or high-demand athletes may experience suboptimal outcomes with direct ligament repair(9,18).

Surgical technique

Arthroscopic portals are systematically established during the procedure. The anteromedial portal is created at the level of the ankle joint line, while the anterolateral portal is positioned approximately 0.5 cm below the joint line and medial to the superficial peroneal nerve. A cannula (PassPort Button cannula, Arthrex, Naples, FL) is introduced through the anterolateral portal to safeguard the superficial peroneal nerve and facilitate the insertion of arthroscopic instruments. Additionally, an accessory anterolateral portal is formed just anterior to the fibula, approximately 0.5 to 1 cm above the tip of the lateral malleolus (Figure 4A). A protocolized arthroscopic evaluation of the ankle joint is recommended to detect all possible intra-articular pathologies.

The ATFL's footprint is identified and debrided (Figure 4B). After identification of the ATFL remains, a suture passer with nitinol loop wire (Microsuture lasso curved 70 degrees, Arthrex, Naples, FL) and a 2.0 nonabsorbable suture (Fiberwire, Arthrex, Naples, FL) is prepared. The suture passer is introduced through the anterolateral portal, and under direct arthroscopic visualization, the ligament is penetrated from lateral to medial. Using Nitinol loop wire through the suture passer, the ligament is grasped and looped with a nonabsorbable suture (Figure 4C-G). Another option to grasp and loop the ligaments is using an automatic suture passer. The ATFL fibular footprint is drilled, and a knotless anchor (Pushlock 2.9 mm × 15 mm, Arthrex, Naples, FL) with the sutures is fixed, reinserting the ligament (Figure 4H).

The postoperative protocol includes full-time use of a removable walking boot with partial weight-bearing for three weeks, followed by three weeks using an ankle brace with full weight-bearing.

Arthroscopic all-inside repair with non-biological augmentation

In recent years, high-strength tapes (non-absorbable sutures) have become popular in orthopedics. Non-biological augmentation for LAL repair was initially described as an open technique using suture tapes after the classical open Brostrom-Gould repair. Later, Vega et al. developed this procedure for a fully arthroscopic technique[45].

Mackay and Ribbans first introduced the concept of suture tape augmentation for Broström or modified Broström repairs using high-strength, non-absorbable suture tape and knotless anchors. This technique enhances the repaired ligaments in a "scaffold-like" manner[51]. In a cadaveric study using 18 fresh specimens, suture tape augmentation of native ATFL increased up to 50% mean load to failure and stiffness compared with the intact ATFL[52]. The original Mackay and Ribbans case series described synthetic augmentation in 49 patients with CAI, which allowed for "early mobilization, reduced pain, and early restoration of function" in a primarily athletic patient population[51].

Vega et al. developed and popularized the arthroscopic AIR with non-biological augmentation. This procedure involves direct arthroscopic AIR, as described above, followed by suture tape augmentation fixed from the tip of the fibula to the talus. It is indicated in patients with CAI with poor-quality remnant ligament[45]. In addition, those CAI with good-quality ligament remnant and high-demand sports activities that demand fast recovery, high BMI, generalized hyperlaxity, combined ankle techniques as osteochondral defect treatment that need mobilization to ensure proper osteochondral healing or hindfoot endoscopy to avoid ankle dorsiflexion stiffness[18].

Using non-absorbable sutures (high-strength tapes) is not risk-free and can sometimes lead to chronic inflammation and a foreign body reaction. Nevertheless, the literature demonstrates some cases of series reinforcing this procedure's safety. Another concern is how tight the suture tape is fixed. Over-tightening the tape can lead to ankle plantar flexion limitation. To avoid this complication, fixing the second anchor on the talus with the ankle in neutral or slight plantar flexion is advised[45].

Surgical technique

The arthroscopic AIR with a knotless anchor is performed as described in the section above. Once the knotless anchor (Pushlock 2.9 mm × 15 mm, Arthrex, Naples, FL) is introduced

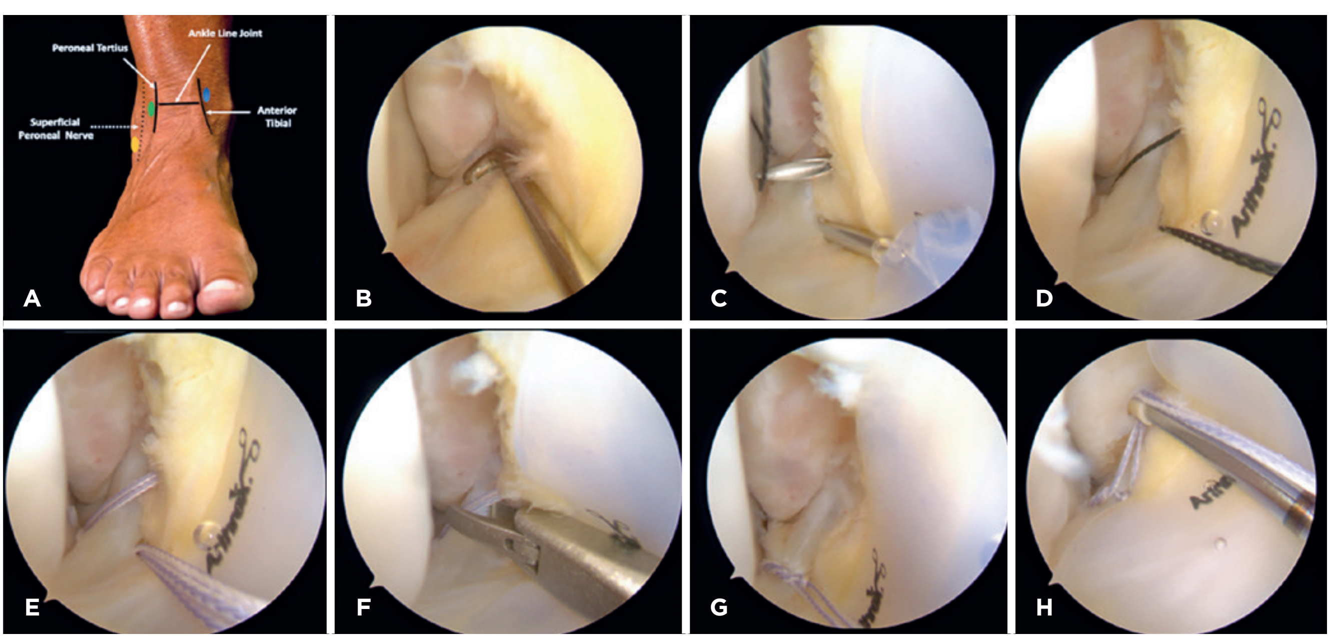

Figure 4. All steps of the arthroscopic all-inside repair.

and the ligament is repaired, the suture remnants (Fiberwire, Arthrex, Naples, FL), are not cut. Using an arthroscopic grasper, the limbs of the suture are pulled out through the accessory portal (Figure 5A). Then, both suture limbs are subcutaneously passed from the accessory portal to the anterolateral portal, returning to the joint (Figure 5B). Once in the anterior tibiotalar joint compartment, the sutures are pulled out through the cannula in the anterolateral portal (Figure 5C).

The talar attachment of the ATFL is identified arthroscopically near the talar neck. The drill guide is introduced through the anterolateral portal and placed at the center of the talar neck, just anterior to the ATFL talar attachment (Figure 5D).

Maintaining the ankle in a neutral or slight plantar flexion position, the Knotless anchor (Pushlock 2.9 mm × 15 mm, Arthrex, Naples, FL) with the sutures is introduced into the hole by impaction. This way, the suture augmentation will not be overtight and will protect the ligament repair. At the end of the procedure, the wires are cut, and the portals are sutured.

The postoperative protocol includes two weeks of partial weight-bearing in a removable walking boot, followed by physical therapy without protection in the third week.

Arthroscopic all-inside repair with biological augmentation

The literature already supports arthroscopic procedures to repair LAL; a recent systematic review demonstrated favorable clinical outcomes of arthroscopic LAL repair in the short term, with functional results like those of the Brostrom-Gould technique. ArtroBrostrom uses the same suture to grasp both ligaments' remnants and inferior extensor retinaculum (IER), while AIR with biological augmentation does it separately.

Cordier et al. presented a case series involving 55 ankles with CAI submitted to arthroscopic AIR supplemented with biological augmentation using the IER. With a mean follow-up period of 29 months, they observed good functional outcomes, as evidenced by improvements in AOFAS and Karlsson-Peterson scores. Complications occurred in five patients (9.1%), including one case of complex regional pain syndrome, two instances of deep venous thrombosis, and two patients who experienced neurological complications[21].

Surgical technique

The arthroscopic AIR repair with a knotless anchor is performed as described in the section above. The next step is biological augmentation using IER.

A second anchor is introduced and inserted proximal to the superior ATFL. A blind trocar is introduced through the anterolateral portal in the subcutaneous space and with a distal and anterior direction to create a working subcutaneous area just above IER.

A third portal is located at the mead-distance of the line connecting the lateral malleolus tip and base of the fifth metatarsal and 1 cm proximal to this point. An automatic suture passer (Mini Scorpion DS Arthrex, Naples, FL) is introduced through the anterolateral portal, charged with one of the suture limbs from the second anchor. The suture passer is directed distally, and the IER is penetrated twice with each suture limb. Sutures are tensioned, and a slighting knot is made to finish the biological augmentation (Figure 6).

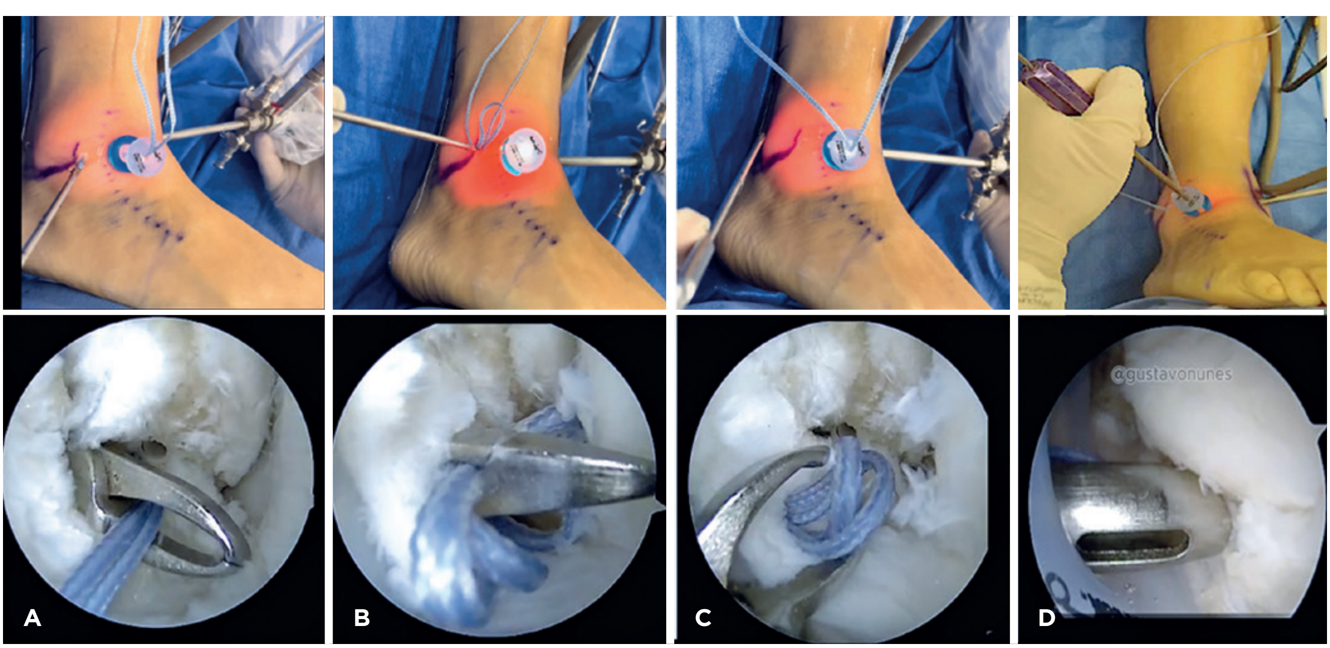

Figure 5. All steps of the arthroscopic all-inside repair with synthetic augmentation.

Endoscopic reconstruction

The ATFL and CFL endoscopic reconstruction is considered a suitable procedure in cases of severe CAI without ligament remnants. This procedure uses an autograft (gracilis tendon) to replace the ATFL and CFL in their native footprints[18]. As with all procedures, this technique was first described using an open approach and later developed using an endoscopic approach. According to the current anatomical description, this technique is not fully anatomical because it does not reconstruct both ATFL fascicles. Nonetheless, the literature has reported that LAL endoscopic reconstruction results in good clinical and functional outcomes[18].

The classical indications for endoscopic reconstruction are poor ligament remnant tissue, no remnant native ligaments, generalized hyperlaxity, high BMI, and revision of previous failed lateral ligament repair. Lateral ankle ligament reconstruction is technically demanding, more morbid, and requires longer patient recovery than arthroscopic repair[18]. With the advancement of lateral repair arthroscopic techniques with suture augmentation, the classical indications for reconstruction have been replaced[53]. The authors consider that the best indication for an endoscopic reconstruction using a graft tendon is to revise a previous failed lateral ligament repair.

Despite being technically demanding and more morbid than arthroscopic repair techniques, this procedure has good results and a low complication rate. Cordier et al. published a case series including 50 patients with a mean follow-up of 31 months. The patients returned to sports at the same level in 84% of the cases. The mean preoperative AOFAS score improved from 76 to 94 points, and the mean Karlsson–Peterson score increased from 73 to 93. There were only two significant complications with the reconstruction's failure (4%)[21].

Surgical technique

Under standardized anteromedial and anterolateral portals, a protocolized arthroscopic evaluation of the ankle joint is performed. A gracilis tendon graft with a minimum length of 11 cm is harvested and prepared. Sequentially, the ligamentous remnants of the ATFL and CFL are debrided, and the fibular footprints are prepared (Figure 7A).

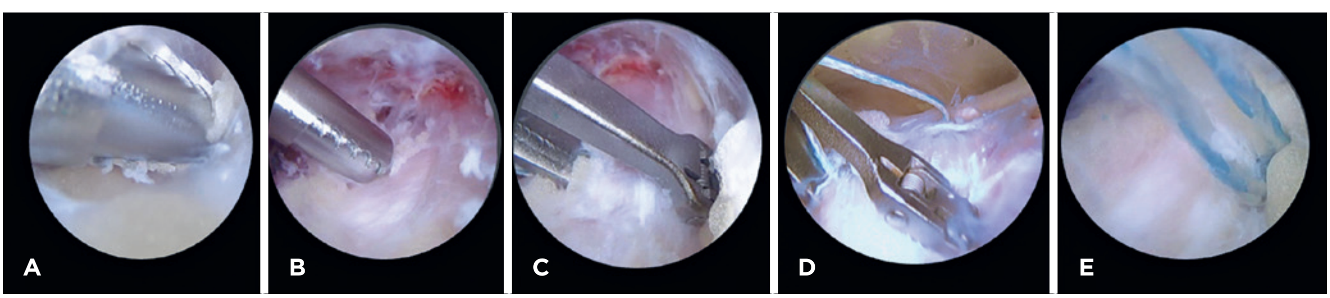

Figure 6. Biological augmentation. (A) Introduction of the shaver under visual control; (B) Creation of working space between inferior extensor retinaculum (IER) and subcutaneous tissue; (C–E) Grasping and suture of the IER.

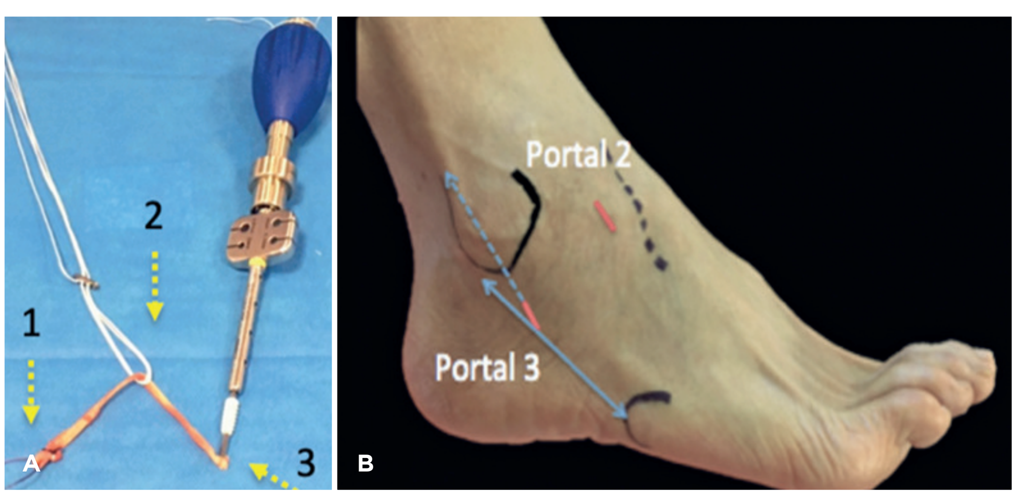

Figure 7. (A) Gracilis graft. (1) Calcaneal side with suture wire; (2) Fibular side with adjustable endobutton; (3) Talar side with tenodesis screw (B) Arthroscopic portals to lateral ligament reconstruction.

A third arthroscopic accessory portal is performed at the intersection of the axis of the fibular tunnel and the superior border of the peroneal tendons (Figure 7B). With the scope in the anterolateral portal and the shaver in the accessory third portal, the dissection is followed until the lateral talus is exposed and the CFL's calcaneal footprint can be visualized. A calcaneal tunnel from the calcaneal footprint to the anterior medial edge of the calcaneal tuberosity is performed (Figure 8). An oblique fibular tunnel (Figure 9) and a talar tunnel are performed by arthroscopic visualization.

The graft is introduced through the anterolateral portal and fixed in the talar tunnel using a 5.5 × 15 mm biotenodesis screw (Tenodesis Screw Biocomposite 5.5 15 mm, Arthrex, Naples, FL, USA) (Figure 10). The other end of the graft is retrieved through the accessory portal and passed through the loop of the adjustable endobutton (ACL Tightrope RT, Arthrex, Naples, FL, USA), which is introduced in the fibular tunnel. The other end of the graft is pulled inside the calcaneal tunnel and fixed with another biotenodesis screw. Holding the ankle in a valgus position at 90 degrees, the endobutton is tightened (Figure 11).

Postoperatively, a walking boot is indicated day and night for four weeks, followed by an ankle brace for two weeks during the day. Partial weight-bearing was allowed after

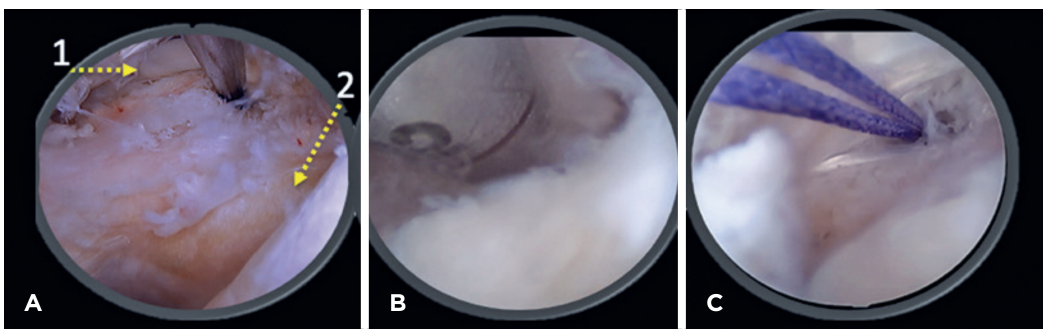

Figure 8. Calcaneal tunnel. (A) Insertion of the guide (1) Fibular tendons; (2) Posterior subtalar joint. (B) Drilling the tunnel (C) Insertion of the suture relay.

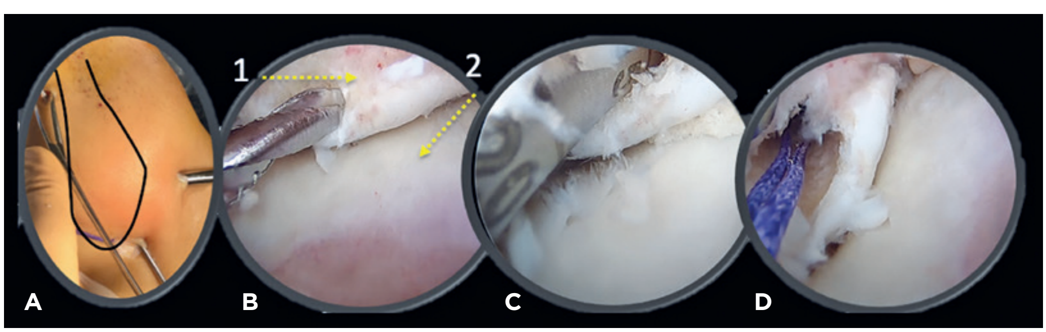

Figure 9. Fibular tunnel. (A) External view. (B) Insertion of the guide. (1) Lateral malleolar "obscure" tubercle; (2) Talar bone. (C) Drilling (D) Insertion of the suture relay.

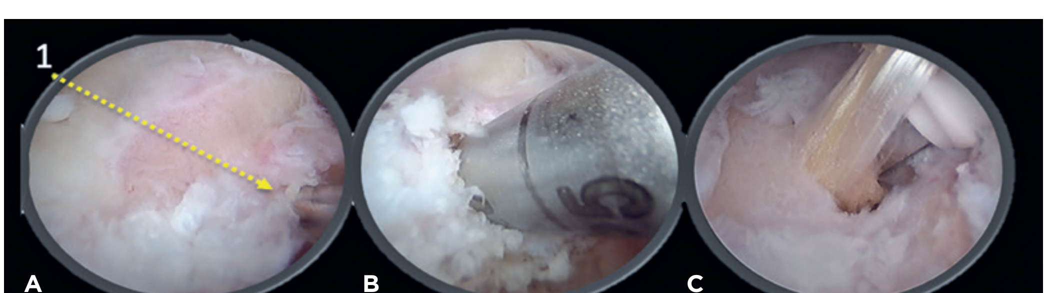

Figure 10. Talar tunnel. (A) Insertion of the guide. (1) Distal ATFL footprint. (B) Drilling over 2 cm (C) Fixation of the graft.

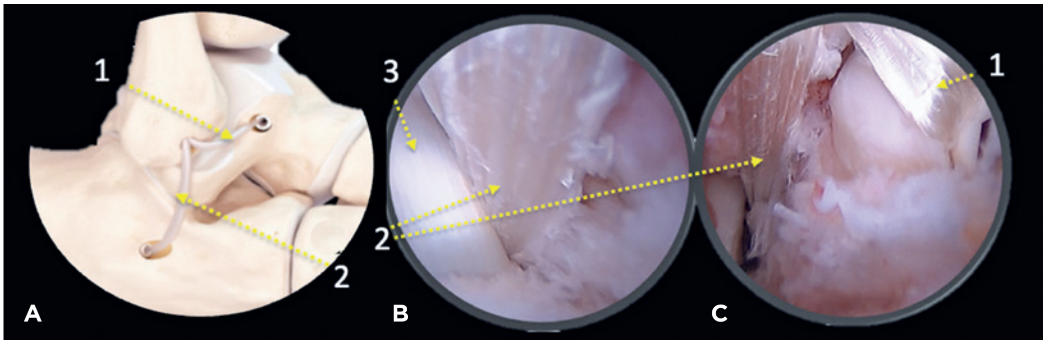

Figure 11. Final view. (A) Schematic view; (B) CFL graft; (C) Complete graft view. (1) ATFL graft; (2) CFL graft; (3) Fibular tendons.

four weeks and progressively to full weight-bearing at six weeks. Physiotherapy was started at four weeks with a strict protocol.

Conclusion

The ongoing developments in understanding the pathophysiology of lateral ankle instability and advancements in surgical techniques and rehabilitation strategies have changed the approach to lateral ankle instability. The low morbidity combined with the restoration of stability and accelerated rehabilitation has spotlighted anatomical arthroscopic techniques. With the growing literature evidence supporting its efficacy and safety, these procedures are becoming the preferred choice for treating lateral ankle instability.

Authors' contributions: Each author contributed individual and significantly to the development of this article: GAN *(https://orcid.org/0000-0003-4431-5576), and TSM *(https://orcid.org/0000-0003-4168-0981), and MG *(https://orcid.org/0000-0003-0671-4648), and MDP *(https://orcid.org/0000-0001-6043-698X), and GC *(https://orcid.org /0000-0002-7035-3931), and JV *(https://orcid.org/0000-0003-2762-8845) Conceived and planned the activity that led to the study, wrote the article, participated in the review process, data collection, bibliographic review. All authors read and approved the final manuscript.*ORCID (Open Researcher and Contributor ID iD.

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Special Article

The art of choosing the right running shoe: a review article

Carolina Romero Cardenas[1]

1. Pontificia Universidad Javeriana, Medsport, Hospital Universitario de la Samaritana, Bogotá, Colombia.

Abstract

This review aims to synthesize current knowledge on running biomechanics, structure and materials of running shoes, and critical factors to consider when choosing the right running shoe to enhance performance and reduce injury risk. A search was performed across major electronic databases, including PubMed, EMBASE, Web of Science, and Google Scholar. Selected studies were then analyzed and synthesized to pinpoint the key factors in choosing the right running shoe, including biomechanics, shoe structure, injury prevention, and the benefits and limitations of different running shoe options. The running shoe choice significantly affects the running performance and injury risk. Key features, such as shoe drop, cushioning, stiffness, and weight must be considered based on the runner's anatomy, gait, and training regimen. Personalized recommendations, informed by a thorough understanding of shoe biomechanics and individual runner needs, are crucial for optimizing the running efficiency and minimizing injuries.

Level of Evidence V; Therapeutic Studies; Expert Opinion.

Keywords: Biomechanics; Foot anatomy; Overuse injuries; Running shoes.

Introduction

Running is a popular current sport, enjoyed by millions worldwide for its physical and mental health benefits. However, its high-impact nature places significant stress on the musculoskeletal system from hips to feet, often leading to injuries. Choosing the right running shoe is crucial for minimizing the injury risk and enhancing performance.

As healthcare professionals, we are familiar with osteosynthesis materials and medical devices, their application technique, and their biomechanical properties. However, as we often walk, run, and wear athletic shoes, knowing and understanding more about such a common element in our daily life as running shoes is essential. Knowing the biomechanics of running and the technology behind running shoes is necessary, especially given the rise of sports and running in recent years. This article reviews the basic principles of running biomechanics, the structure and materials of footwear, and the characteristics to be considered for choosing running shoes correctly.

Running has grown in popularity each year, with a significant increase in races and competitors. Data shows an increase in the number of runners, although the average time to finish a marathon is also increasing. A recent article about the New York Marathon reported that, in 2016, there were approximately 23,000 registered runners, with an average time of 4 hours and 23 minutes to finish the race. In 2022, there were approximately 40,000 registered runners, with a final race time of 4 hours and 50 minutes. What does this show us? There are more and more amateur runners and beginners in this sport, therefore, more people require proper running shoes. These competitors are at an elevated risk for overuse injuries, as most amateur and novice runners share

Study performed at Pontificia Universidad Javeriana, Medsport, Hospital Universitario de la Samaritana, Bogotá, Colombia.

Correspondence: Carolina Romero Cardenas. Cra. 8 #0-29, Santa Fé, Bogotá, Colombia. **Email:** cromerocardenas@gmail.com. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** July 2, 2024. **Date accepted:** July 2, 2024. **Online:** August 30, 2024.

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three main risk factors for injury: (1) lack of musculoskeletal system strength and conditioning, (2) undirected and progressive sports training, and (3) inadequate equipment, particularly running shoes.

The sports footwear industry is a high-tech benchmark, having undergone significant changes in the last 50 years in terms of structure, technology, and materials engineering. Some studies support these advances, not only from the sports performance point of view, but also in the biomechanics applied to different types of footwear and their biomechanical characteristics. However, there is a fashion and marketing boom behind this innovation, and marketing strategies or flashy models should not bias us.

Therefore, we must recognize the characteristics of running shoes, how to apply them to the foot biomechanics, and the possible pathologies associated with the sport. In addition, we must prevent overuse injuries. From a sporting point of view, the goal is to make running more efficient. Efficiency is the best performance (faster speed) with the lowest energy consumption (VO2), and recent literature has also included the concept of injury prevention within efficiency. The industry seeks to design running shoes with cushioning, stability, lightness, ground responsiveness, comfort, and an attractive design.

This review provides an evidence-based guide to help healthcare professionals and runners select the most appropriate footwear based on current orthopedic research and biomechanical principles.

Methods

Identifying the research question

The following research question guided the review: What biomechanical factors should be considered when selecting the best running shoe?

Identifying relevant studies

The search used PubMed, EMBASE, Web of Science, and Google Scholar. Search terms covered the population and outcomes relevant to the research question. Overlapping terms were included to ensure the broadest possible scope of studies was identified by searching the electronic databases (Table 1). The search was carried out between September and November 2023.

Table 1. Search terms used

Population	"Shoe"[Majr] OR Foot Orthoses, Arch Support, Foot OR Foot Orthotic Device
AND	"Biomechanics"[Mesh] Biomechanical Phenomena, Kinematics OR Mechanobiological Phenomena, Physical Phenomena
AND Outcomes	Impact [All Fields]

Study selection and data charting

Data was extracted and tabulated in Microsoft Excel (2019). Two templates were generated for this stage. The first template plotted descriptive data for each study: authors, year of publication, country of publication, study design, setting, sampling method, sample size and composition, and materials used. Subsequently, a second template was created for duplicate data extraction and to reassess the information, addressing any discrepancies.

Collating, summarizing, and reporting results

The heterogeneity of methodologies used required a qualitative synthesis of research results rather than a quantitative meta-analysis. No formal assessment of study quality was performed, which was consistent with the nature of this kind of review.

Results

Search results

Initial search yielded 7,432 results; after refining the search and eliminating duplicates, 3,020 documents remained for analysis. Of these, 2,875 are indexed in PubMed.

Finally, after applying the inclusion criteria (Table 1) and eliminating studies that did not assess the shoe impact on biomechanics, 13 studies were reviewed and included in the analysis.

Synthesizing the results

Applied concepts of walking and running

Gait results from a series of forces that act together, allowing the body to move forward with the minimum energy consumption.

Determinants of gait are the interaction of anatomical structures and forces that act synergistically to decrease muscle contraction and allow displacement in gait. This reduces the oscillation of the center of gravity in the sagittal plane and the rotation of the pelvis in the coronal plane, decreasing muscle action and thus improving metabolic expenditure.

Foot anatomy and biomechanics

The foot is a complex structure comprising 26 bones, 33 joints, and over 100 muscles, tendons, and ligaments. Vital anatomical features include the arch, heel (rearfoot), and forefoot, each playing a critical role in shock absorption and propulsion during running. Understanding the biomechanics of running, including the gait cycle phases (stance phase and swing phase), is essential for selecting shoes that complement natural foot movements and reduce the injury risk.

Gait determinants

Among the determinants of gait, we include[1] the center of gravity, which, in the human body, is located on the anterior face of the third lumbar vertebral body[2]; the support polygon, an imaginary space delimited by the external area of support for the feet[3]; and the axis of gravity that passes through the center of gravity and falls at the center of the support polygon[4]. Ground reaction force (GRF) is the force exerted by the ground on the body upon coming into contact with it (Figure 1.A). It is given by Newton's 3rd Law, concerning "action-reaction:" when a force is applied to a surface, it is returned to the body and generates the movement.

Gait phases

Gait has two main phases: the stance phase, which corresponds to 60% of the gait cycle, and the swing phase, which corresponds to 40% of the gait cycle (Figure 2). In running, these proportions are reversed, with the stance phase corresponding to 30% of the gait cycle and the swing phase, to 70%; this varies according to the speed of run – the higher the speed, the longer the swing phase[1]. In addition, a third

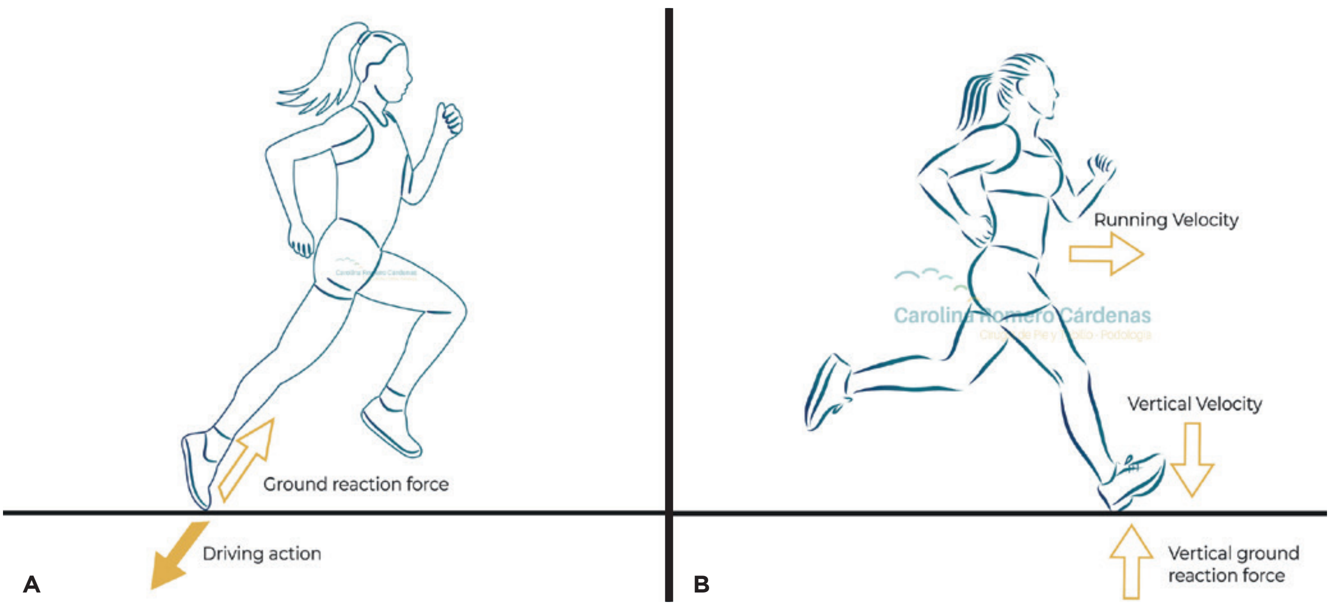

Figure 1. (A) Ground reaction force: the force exerted from the earth's center on the body upon coming into contact with it (B) In the contact phase, the objective is to respond to and absorb the ground reaction force, the force of gravity, and body load.

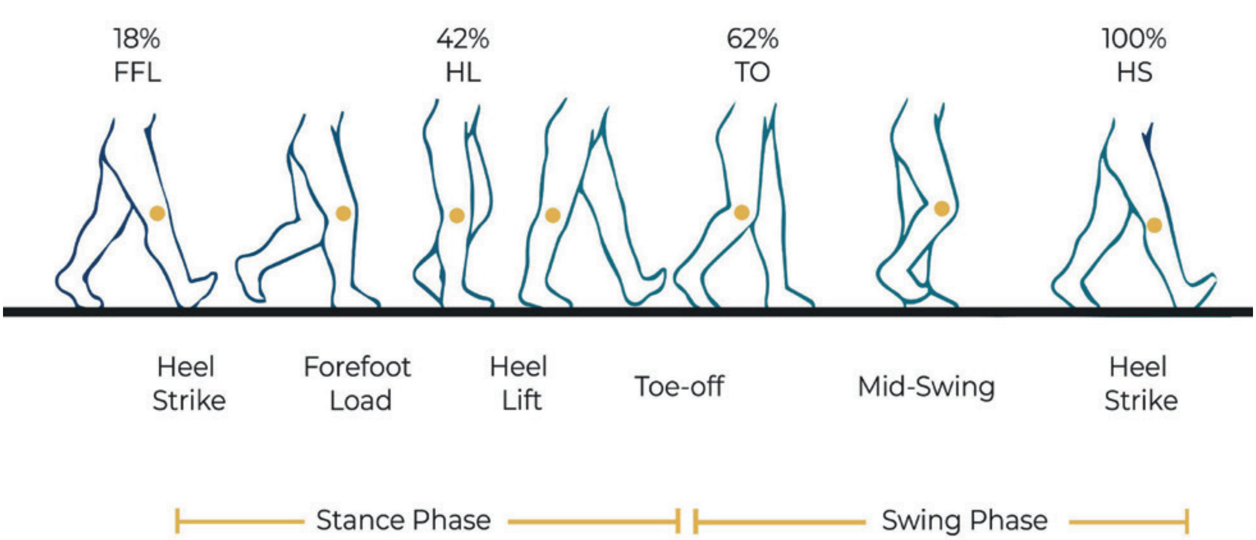

Figure 2. The gait cycle has two main phases: the stance phase, which corresponds to 60% of the gait cycle, and the swing phase, which corresponds to 40%.

phase is added in running: elevation "float" or "double elevation," where both feet are suspended in the air at the same time.

The contact phase (stance phase) is 30% of the cycle, but it is where running shoes come into play. It is subdivided into three phases: initial contact, mid-stance, and propulsion.

The contact phase goes from the initial heel strike to full forefoot strike. The objective is to respond to and absorb the GRF, force of gravity, and body load (Figure 1.B)[4]. The rearfoot is supported in six degrees of varus, pronated until the forefoot is in contact with the ground[3] (Figure 3). The initial contact occurs on the external edge of the heel, in 6 degrees in varus position; this is the reason for the normal pattern of postero-external wear of shoes.

The second phase, mid-stance, goes from the full foot strike to the beginning of heel rise. Here, the midfoot has helical movements. The subtalar joint supinates to turn the rearfoot into a rigid lever, which prepares us for the propulsion phase. There is also an anterior displacement of the load vector of the limb, moving the tibia and knee anteriorly[1].

The third take-off, or propulsion phase, starts with the heel take-off and continues until the digital take-off. A concentric contraction of the ankle flexors, added to the foot's intrinsic and the ground's reactive forces, allows the anterior propulsion[4].

Foot strike

In running, the type of footprint, or the way the foot contacts the ground when running, has been described in three types:

a. **Heel strike**: When the ankle is in dorsiflexion, the forces of impact in rotation cannot be transferred to the legs. There is also a greater energy absorption in the distal tibia, with a greater risk of shin splint. As the ankle is rigid, there is less load on the foot and on the Achilles tendon.

b. **Midfoot support**: The ankle position is neutral, ankle stiffness decreases, and there is a better load distribution in the foot and distal tibia. This makes it the most metabolically economical type of foot strike.

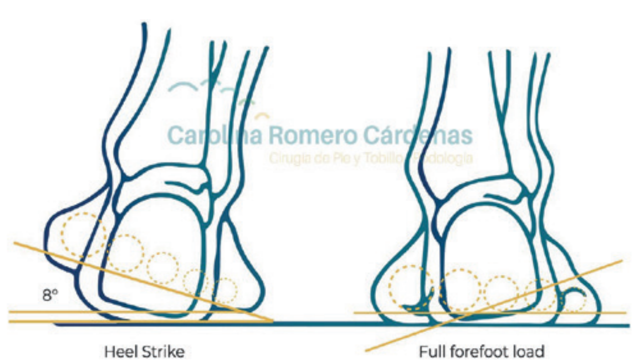

Figure 3. The rearfoot is struck in 6 degrees of varus, and the forefoot is elevated. The pronate until the forefoot is in contact with the ground.

c. **Forefoot support**: The ankle's position is in slight plantar flexion. A more significant load on the Achilles tendon and calf decreases the proximal load on the distal tibia, with a better elastic energy use, favoring the speed in the race.

In beginners, support is usually on the heel, which favors the appearance of injuries due to overuse and overload of the distal tibia. Strength training and running technique exercises can modify the type of stride over time and progressively improve the stride and running gesture[4,5]. However, it is not possible to alter the kind of stride voluntarily, suddenly, or to try to perform a foot strike that is not physiological, because this leads to an overload of the lower extremities.

Shoe anatomy

In most cases, the construction of running shoes is comprised of the following parts[5] that fulfill specific functions (Figure 4):

- **The heel counter or buttress:** it gives support to the heel; this can be soft or more rigid and controls the stability of the heel;
- **The heel:** height of the sole in the back that determines the drop;
- **The sole and midsole:** midsole are layers of thermoformed materials that form the middle of the sole; it fulfills the function of cushioning and is covered by the sole, which is the outermost portion of the shoe that provides protection and controls the friction to the ground;

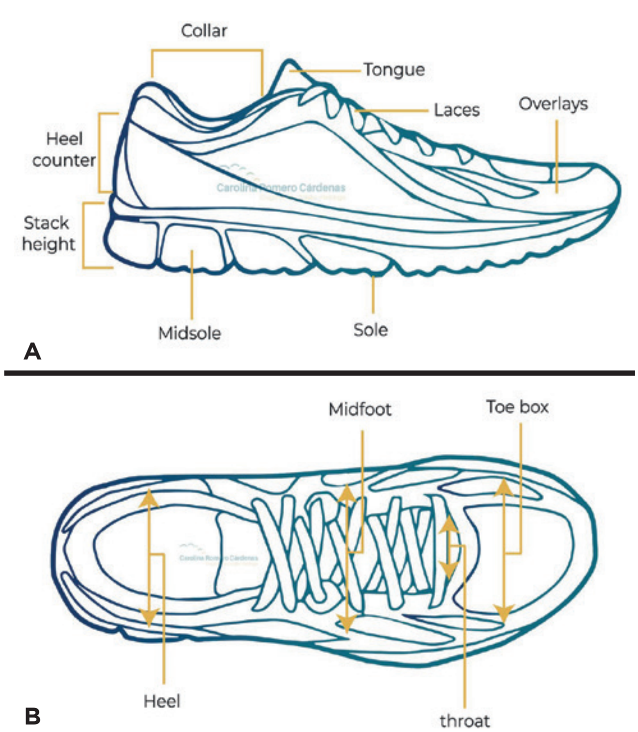

Figure 4. Anatomy of the running shoe (A) Lateral view (B) Top view.

- **The heel flare:** posterior angulation of the medial or lateral heel. The standard angle is 15º. The greater the medial or lateral heel flare, the greater the stability;
- **The upper:** material covering the foot;
- **The toe box:** the most anterior portion where the forefoot is housed;
- **The heel tab:** the tongue at the back of the shoe that helps put on the shoe and protects the Achilles tendon; and
- **The neck collar:** located on the back of the shoe, it adjusts the ankle, tongue, holes, and laces.

What are "pronator" or stability shoes?

These are shoes designed to promote a greater internal control of the foot's movement in contact phase and mid stance. (Figure 5). They are helpful for people with valgus rearfoot, flat feet, and pronation during walking. They are characterized by having materials of greater density (greater hardness) in the medial portion as wedges or arches of support in the rear portion of the heel. This results in a lower medial arch of inclination (pronation) during walking and provides stability. Due to the density of the materials, they are usually heavier shoes.

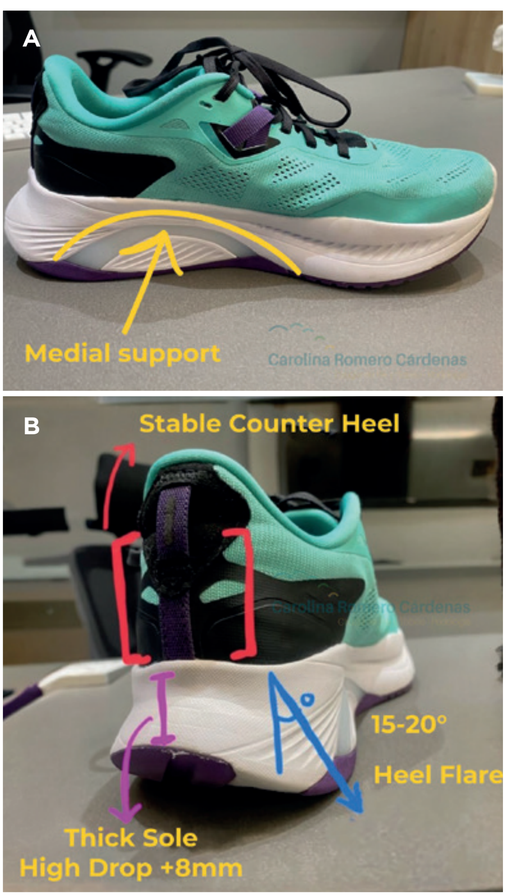

Figure 5. Pronator of stability shoes: characterized by having materials of greater density in the medial arch as wedges or arches of support in the rear portion of the heel. Also, with thick soles, the counter heel is more stable and has a wide heel flare, providing stability.

Which footwear structure characteristics have been studied?

Significant changes have been made in the biomechanics of running in shoes.

Few studies have been conducted on shoe construction; no study shows one shoe "construct" as being superior to another. Literature focuses on the relationship between performance and injury prevention. Two systematic literature reviews by Lin et al.[2] and Sun et al.[2,5] about footwear science describe the characteristics of a shoe, its function, its modifications in the biomechanics of running, and whether it has been shown that these structures can prevent the occurrence of injuries.

Which shoe structure variables or features provenly improve performance and decrease the risk of injury according to the literature?

The most reviewed variables are the drop, hardness, cushioning, stiffness, bending stiff, weight of the shoe, and height (thickness) of the sole.

Other characteristics less reported in the literature include heel flare, laces, number of lace holes, shoe fit, stiffness of the upper, and heel cup[5].

- **Midsole**: This is formed by foam layers (Figure 6), normally thermoformed materials, which means their properties are modified by heat and pressure; the most commonly

Figure 5. The midsole is formed by layers of foam that provide cushion; in between, some shoes provide more rigid materials such as carbon plates or TPU that provide stiffness.

used materials in the market are ethyl vinyl acetate (EVA) and polyurethane (PU), and their main characteristic is to provide cushioning. Densities of elastomeric materials can be divided into high, medium, or low according to the Asker scale (Ask C), done with a durometer measuring system; for example, AskC 50 is a mid-high-density material. Each company has developed and patented its own branded foams, such as Lightstrike Pro (*Adidas, Adidas, DEU*), Fuelcell (*New Balance, New Balance Athletics, Boston, MA, USA*), and Zoom X (*Nike, Nike, Inc. Oreg, USA*), among others.

The EVA is a less dense material that loses its properties under load (it wears out more). Fewer mechanical changes are seen in PU, therefore, it lasts longer. Literature indicates that the harder the midsole, the greater the reactivity to the ground, the better the take-off, and the better the medial stability control (pronation)[2,5].

- **Stiff materials and bedding stiff: carbon plates and thermoplastic polyurethane:** Recently, more rigid and light materials have been developed, such as carbon plates or thermoplastic polyurethane (TPU) (Figure 6). The "latest technology" shoes or the new "super shoes" have emerged, where layers or bars of these light and rigid materials are introduced, promoting a *bending stiff* characteristic: the resistance of a material subjected to bending. They improve the reactivity of the foot when in contact with the ground and favor the GRF take-off [6]. Several studies show that elite runners using shoes with carbon plates (Nike Vaporfly - Nike, Inc. Oreg) improve performance by 4% to 6% in comparison with shoes without carbon plates; they improve stride length and decrease the center of gravity oscillation[6,7]. They also improve VO2 and runner performance. It has been shown that the stiffer the material, the better the response to the GRF, improving propulsion, reducing the forefoot impact, and increasing ankle plantar flexion at toe-off[6]. Although they improve running performance, there are no studies showing injury prevention.
- **Sole:** The outermost portion; it is usually made of rubber or similar materials. These provide grip, control friction to the ground, and give the shoe durability. Each company has also developed alliances with different companies, such as Sketchers (*Skechers, CA*) with Goodyear, and Adidas (*Adidas, DEU)* with the Continental brand.
- **Sole thickness/height:** The higher the sole, the greater the vertical load absorption and the greater the material's durability. It promotes an improved plantar pressure, which is the sensation of feeling the sole "in contact" with the ground[2].
- **Weight:** It affects the running economy. It may sound logical – the heavier the shoe, the greater the metabolic expenditure; it has been shown that 100 g increases VO2 by 1%. Therefore, the lighter the shoe, the lower the energy consumption. For example, a stable neutral shoe for daily training, such as the Brooks Ghost (*Brooks Sports, WA*), weighs approximately 298 g, while the Hoka Carbon X3 (*Hoka, CA*) weighs 198 g, a lighter shoe with a greater reactivity for race day.
- **Heel flare:** The more significant the lateral angle, the greater the lever arm. Thus, the arc of movement is more critical when the rearfoot makes varus contact and initiates pronation to achieve the hole forefoot support. There is a greater pronation control when the flare is medial, while the lateral flare improves axial load in contact. No changes in ankle kinematics have been demonstrated, nor are there studies that show injury prevention.
- **Drop:** It is the shoe sole inclination, given by the difference in millimeters between the heel and the forefoot. If the heel measures 35 mm and the forefoot, 26 mm, the shoe drop is 9 mm. Shoes are divided according to the drop into high: 8 mm–10 mm, medium: 5 mm–8 mm, low: 1 mm–4 mm, and zero: 0 mm. The drop affects the impact of the foot contact with the ground, the distribution of loads on the foot, knee, and hip, and the foot take-off.

When the drop is high, the arc of mobility of the ankle decreases (up to 5º). This reduces load absorption in the foot, ankle, and Achilles tendon, with load being transferred to the distal leg and knee. It favors heel strike and increases tibial acceleration[7] (Figure 7A-B). In the low drop, there is a greater arc of ankle mobility in dorsiflexion. This favors midfoot and forefoot support, absorbs a more significant impact, and makes the footwork a spring. Load on the hip, gluteus, iliotibial band, and knee is decreased. It has been shown to improve the running chain[7] (Figure 7C-D).

Therefore, high-drop shoes are indicated in patients with foot and ankle pathology to protect them. These are also useful in beginners in running, since their musculoskeletal and articular systems are not yet adapted to support the running load. In addition, this type of runner usually starts running with a heel-supported running technique, so the high drop decreases the load on the foot.

On the other hand, medium- or low-drop shoes are better tolerated by more experienced athletes, since their musculoskeletal system is adapted to the load and the running technique used has been developed to support the midfoot and forefoot. Therefore, the more proximal knee and hip region are protected from impact. Zhang et al.[8] conducted a study on female runners showing that high-drop shoes (10.5 mm) increase the knee extension moment in the mid-stance phase and the patellofemoral stress area. Therefore, for patellofemoral pain ($p = 0.003$), it is suggested using medium-low drop shoes.

How can we apply this information?

Not all shoes are meant for all athletic activities, and not all shoes are for everyone. How to choose the correct shoe? Three variables must be considered:

1. What is the type of activity?
2. How is the physical examination of the running patient?
3. Does the patient suffer from previous sports or overuse injuries?

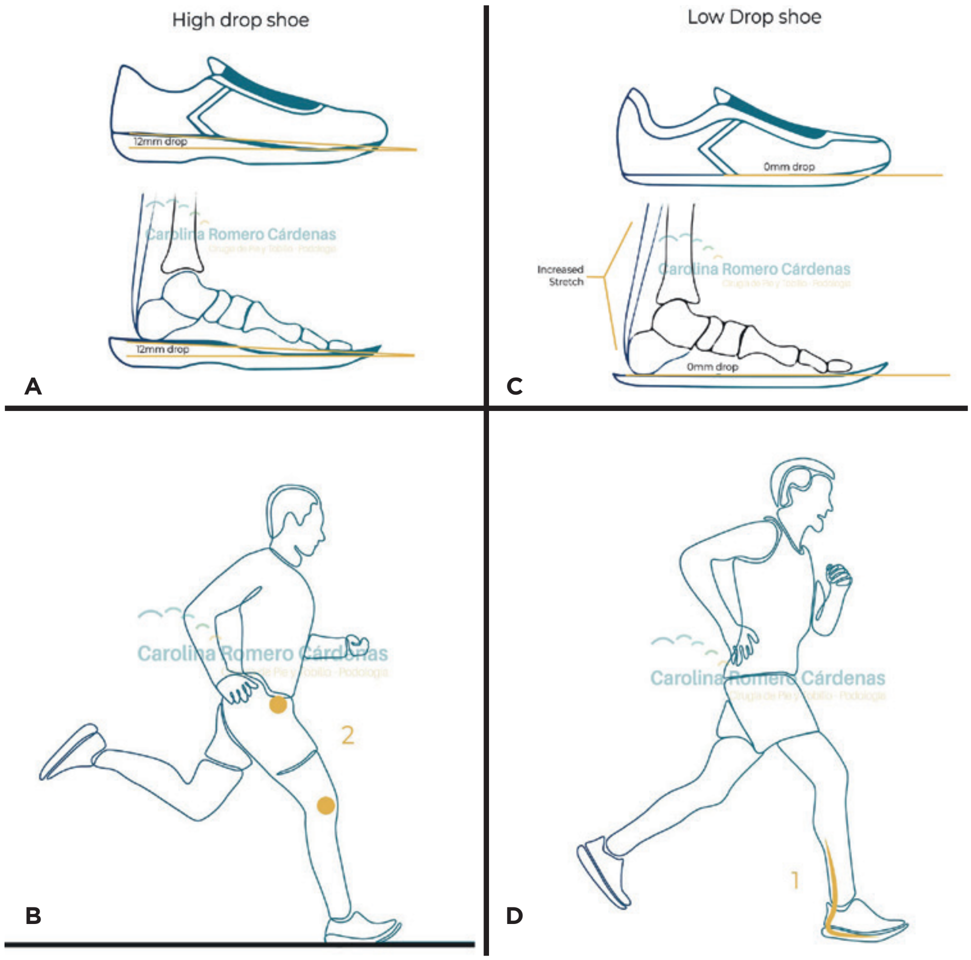

Figure 7. (A) High drop shoe: position of foot, ankle, and Achilles tendon (B) High drop shoes reduce load absorption in the foot, ankle, and Achilles tendon; the load is transferred to the distal leg and knee (C) Low drop shoe: position of foot, ankle, and Achilles tendon (D) In low drop shoe midfoot and forefoot absorb more significant impact.

In running, there are different types of "activities" or workouts that require different shoe types, which can be grouped as:

a. Shoes for daily training (daily trainer) or easy run shoes;
b. Shoes for long run training;
c. Shoes for interval or speed training (e.g., track training); and
d. Shoes for competition or race day.

From this arises the concept of "shoe rotation." It has been shown that rotating or alternating at least two pairs of shoes adapted to each activity decreases the training load, improves performance, prevents injuries, and optimizes the technology (cost-benefit) when used for the indicated activity.

Example of "shoe rotation" options currently available on the market: a) easy run shoes, NB 10180 (*New Balance Athletics, Boston MA)* – stable, with adequate cushioning, high drop; b) long-distance shoes, Adidas Boston 12 (*Adidas, DEU)* – high drop, good rearfoot cushioning, reactivity in the forefoot portion; c) interval/speed shoes, Hoka Match X (*Hoka, CA)* – medium drop, medium carbon midsole in forefoot, light; d) competition shoe, Nike Vaporfly (*Nike, Inc. Oreg)* – carbon plate, medium-high drop, lightweight, very reactive.

A physical examination by a specialist physician or physiotherapist is essential (Figure 8), examining patient while standing and walking. It must evaluate the heel in contact and mid-stance phase further evaluating the structure of the foot – neutral foot, valgus flat foot, or supinated pes cavus. The constitution and weight of the patient are also essential[9]. This guides us to choose a neutral or stable shoe (shoes for pronators). For example, shoes such as Brooks Glycerine (*Brooks Sports, WA)*, neutral shoes with high soles and high density, would be ideal for a person with a thick and large constitution; on the other hand, the top-of-the-range shoes Nike Alpha Fly 2 (*Nike, Inc. Oreg)* are shoes with beveled heels and lightweight for people with the high pace

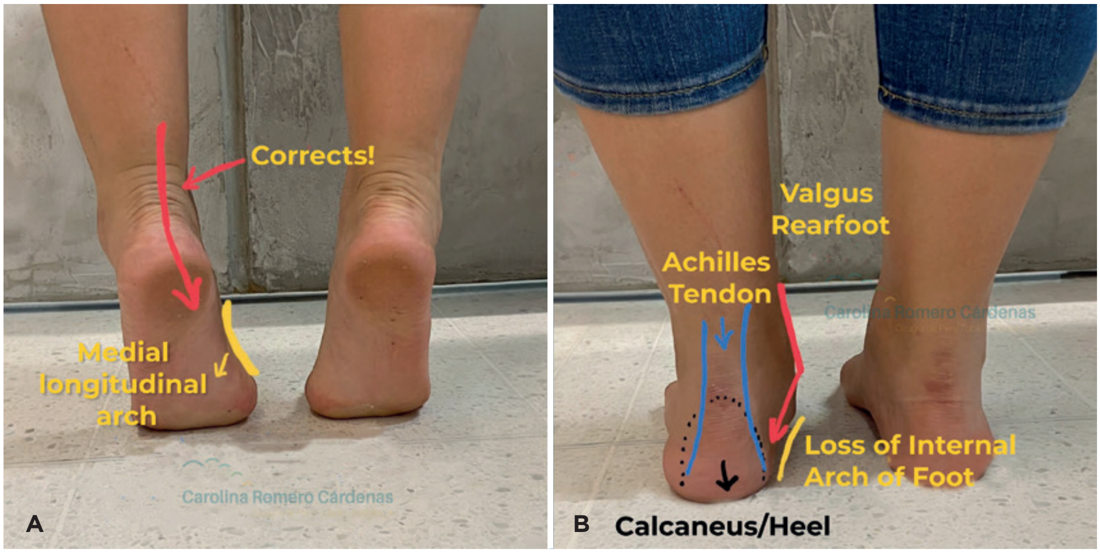

Figure 8. Physical examination should be performed while standing and walking. An example is a hind foot valgus.

of a light constitution. In turn, performing a proper anamnesis and evaluating musculoskeletal injuries or previous overuse injuries is also important. Among the most frequent injuries in runners are stress fractures, splints shinst, patellar tendonitis, plantar fasciitis, and Achilles tendonitis[10].

What would be the ideal shoe?

No ideal construct has been described in the literature[2,5]. There are many studies on running biomechanics, overuse injury prevention, running efficiency, and shoe materials. However, there is little literature on how to guide our athlete patients in choosing an ideal shoe, especially for amateur runners just starting out in the sport. As runners become more experienced, not only does their musculoskeletal system adapt to the load, but they also recognize what type of shoe they can choose during different types of training[11].

In my idea as a physician and amateur runner, an ideal shoe for beginners or experienced amateur runners who want a shoe for daily training (daily trainer) and long-distance races should have the following characteristics[11,12]:

1. Neutral, with adequate stability. Only pronator shoes for runners with flat feet and pronation in contact phase and mid-stance phase;
2. Medium–high drop (7 mm–10 mm). This provides better shock absorption and ankle and foot protection[12,13];
3. Adequate cushioning. Rearfoot with an adequate load absorption capacity and forefoot with stiffer and lighter materials that favor the release and reactivity to the ground.
4. Long-distance training. For daily use (daily trainer) or for long-distance races.

Discussion

Choosing the right running shoe is paramount for enhancing performance and preventing injuries among runners. This review highlights the critical interplay between shoe design and running biomechanics. The intricate structure of the foot and the phases of the gait cycle underscore the necessity for footwear that complements natural foot movements while mitigating the risk of overuse injuries.

The review outlines the essential components of running shoes, such as the midsole, heel, upper, and outsole, each contributing to the overall functionality and comfort of the shoe. The midsole plays a pivotal role in cushioning and shock absorption, with materials like EVA and PU offering varying levels of durability and responsiveness. The integration of advanced materials, such as carbon plates and TPU, has led to the development of “super shoes” that enhance running efficiency by improving ground reactivity and reducing energy expenditure.

The discussion on shoe drop highlights its significant impact on load distribution and injury prevention. High-drop shoes benefit beginners and those with foot and ankle pathologies, as they reduce the load on these areas. Conversely, experienced runners may benefit from low- to medium-drop shoes that promote a more natural running gait and protect the proximal knee and hip regions from impact.

Shoe rotation is another critical concept that emerged from this review. Alternating between different pairs of shoes tailored for specific training activities can reduce training load, enhance performance, and prevent injuries. This approach underscores the importance of selecting shoes based on the type of running activity, from daily training to competition.

The practical application of these findings involves thoroughly examining the runner, considering factors such as foot structure, weight, and previous injuries. This personalized approach ensures that the recommended shoe type aligns with the runner's biomechanical needs and training goals.

Despite the advancements in shoe technology, there is no universally ideal running shoe. The optimal choice varies based on individual biomechanics, running style, and specific needs. It is crucial that future research shifts its focus to longitudinal studies. These studies can provide valuable insights into the long-term effects of different shoe constructs on performance and injury rates among diverse populations of runners, not just elite or professional runners.

In conclusion, the art of choosing the right running shoe lies in understanding the intricate relationship between shoe design, foot biomechanics, and individual running requirements. By applying biomechanical principles and leveraging advancements in shoe technology, healthcare professionals play a crucial role in providing informed recommendations. These recommendations can significantly enhance running efficiency and reduce the risk of injuries.

Strengths and limitations

This review comprehensively analyzes the relationship between running shoe design and running biomechanics, offering valuable insights for healthcare professionals and runners. One of its key strengths is the detailed examination of the anatomical and biomechanical factors that influence running efficiency and injury prevention. By synthesizing information from various studies, the review highlights critical components of running shoes, such as midsole materials, shoe drops, and advanced technologies like carbon plates. This allows a more informed understanding of how these factors contribute to runners' overall performance and safety.

Additionally, the practical recommendations for shoe selection based on individual biomechanics and running activities are a significant strength. This personalized approach can guide healthcare professionals in advising runners on the most suitable footwear, potentially reducing overuse injuries.

However, this review also has limitations. The rapidly evolving nature of running shoe technology means that innovations and materials may need to be fully covered. Furthermore, reliance on existing literature implies that the quality and scope of previous studies constrain the review. Many of the studies reviewed have focused on elite athletes, which may limit the generalizability of findings when it comes to amateur runners. Additionally, there is a need for more longitudinal studies to assess the long-term effects of different shoe constructs on performance and injury prevention.

Future research recommendations

Future research should focus on longitudinal studies assessing the long-term effects of different running shoe constructs on performance and injury prevention across various populations, including amateur and recreational runners. More comprehensive studies are needed to evaluate the impact of emerging technologies and materials in running shoes, such as carbon plates, advanced cushioning systems, and sustainable materials.

Additionally, research should investigate biomechanical differences in running mechanics among diverse demographic groups, including age, gender, and body types, to determine how personalized shoe recommendations can be optimized for each individual. Studies should also explore the effects of different training regimens in conjunction with various types of footwear to better understand how shoe characteristics affect training outcomes and injury risk over time.

Finally, interdisciplinary research involving collaborations among biomechanics specialists, podiatrists, orthopedists, and sports scientists could provide a more holistic view of the interaction between footwear and human biomechanics. This would help develop more precise guidelines for selecting running shoes tailored to individual needs, enhancing performance and reducing injury rates among runners.

Other recommendations

Currently, the market offers various running shoe options, and it is not easy to know their characteristics. But, nowadays, there is non-medical literature available with very accurate and good-quality information that allows us to quickly review the characteristics of shoes, enabling us to suggest and guide our patients. I dare to suggest some non-medical accounts updating the boots on the market, such as https://www.runnea.com/, @doctorsofrunning, and https://solereview.com, among others.

With these sources, you can evaluate general characteristics, such as gender, weight, drop, cushioning, stability or neutrality, patient's constitution, type of footprint, use of the shoe (competition—training), technology (with carbon plates or TPU), forefoot support, distance to run, reactivity, and shoe flexibility.

Conclusion

Running is a booming sport worldwide, and more and more patients are consulting for musculoskeletal injuries and asking for advice on purchasing running shoes. The variety in the market is vast, and we should not be guided only by fashion or flashy models. Behind every design, literature and studies provide valuable information about the shoe structure and biomechanics.

Health professionals should focus their recommendations on the patient's activity, perform a thorough examination, and evaluate previous injuries caused by overuse. It is critical to guide the patient to the best shoe option that suits their needs.

The right running shoe can improve a runner's performance, prevent injuries, and promote a healthier and safer running experience. The running shoe industry has advanced significantly, offering products that combine advanced technology with ergonomic design. Leveraging these advances and applying biomechanical knowledge in clinical practice is essential to provide the best advice to our running patients.

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Special Article

Müller-Weiss disease: the state of the art

Wellington Farias Molina[1], Erika Saori Gushiken[1], Guilherme Bottino Martins[1], Lourenço Galizia Heitzmann[1], Luiz Sérgio Martins Pimenta[1], Elizabeth de Alvarenga Borges da Fonsêca[1], Gustavo Demasi Quadros de Macedo[1]

1. Hospital do Servidor Público Estadual de São Paulo (HSPE), São Paulo, SP, Brazil

Abstract

Müller-Weiss disease generates complex biomechanical changes in the feet, and although it is a rare disease, its true prevalence is not known. In addition to the low population incidence, some cases remain asymptomatic, which contributes to the disease being underdiagnosed or even unknown by the general orthopedist. Its most striking clinical feature results from the combination of paradoxical flatfoot with insidious midfoot pain, resulting in different degrees of difficulty for ambulation and progressive collapse of the plantar arch. Treatment begins with the conservative approach, and surgical treatment is indicated when failure occurs. In this review, we intend to clarify the subject, as misunderstandings or delays in diagnosis negatively impact treatment outcomes by worsening anatomical changes and functional deviations that arise from these issues. There are few studies on this disease, most of them being case series, which highlights the need to concentrate on performing multicenter studies that can collaborate in clarifying the numerous issues involving this deformity. In summary, Müller-Weiss disease is rare and complex, with its etiological characteristics and treatment still lacking consensus in the literature. Due to the absence of validated therapeutic algorithms, we continue to adopt individualized treatment for each foot, tailored to the specific characteristics of each patient.

Level of evidence V; Therapeutic studies - investigating the results of treatment; Expert opinion.

Keywords: Necrosis, Avascular, of Bone; Flatfoot; Tarsal bones; Review literature; Treatment.

Introduction

Müller-Weiss disease (MWD) is a rare condition that affects the navicular bone, resulting in progressive collapse and deformity of the plantar arch[1,2]. Its etiology is not completely understood, but it is believed to be multifactorial[3], involving both genetic factors (previous anatomical deformities such as metatarsal adduct and hindfoot varus) and biomechanical factors (athletes with exhaustive training in high-impact sports and requiring rapid and successive changes of direction in childhood and adolescence as occurs in tennis, football, etc.)[4], as well as nutritional aspects, such as environmental stress (wars, droughts, floods) and epidemics (consumer diseases, malnutrition) with individual action during childhood and, in some cases, adolescence[2,3,5-7].

Therefore, including this disease in the differential diagnosis for patients presenting with painful foot complaints and progressive deformity of the plantar arch is crucial[8]. Early diagnosis and appropriate treatment are essential to prevent complications and improve the quality of life for affected patients.

State of the art

Although evidence of MWD was found in Ancient Egypt[9], only in 1927 Walter Müller described it in a patient with severe tarsal navicular deformities. The radiographic changes characterized by sclerosis, thinning, and bone fragmentation, were attributed to compressive forces in the tarsus[1,2]. In the same year, the Austrian radiologist Weiss[10] described two other similar cases, and from then on, the disease became known as Müller-Weiss disease, although Schmidt[2,6] published a similar case about a patient with endocrinopathy. Müller in 1928[11] proposed that clinical and radiographic changes began in childhood due to some congenital defect, not associated with trauma, based on the

Study performed at the Hospital do Servidor Público Estadual de São Paulo (HSPE), São Paulo, SP, Brazil.

Correspondence: Wellington Farias Molina. Rua Borges Lagoa, 1755, 1º andar, Vila Clementino, São Paulo, SP, Brazil. **Email**: wellmolina@gmail.com **Conflicts of interest**: none. **Source of funding:** none. **Date received:** June 30, 2024. **Date accepted:** August 12, 2024. **Online:** August 30, 2024.

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finding of histologically normal tarsal navicular. However, in 1927, Weiss, who had worked with Robert Kienböck, believed that the main cause of the disease was osteonecrosis of the tarsal navicular[12].

In 1939, Brailsford[13] considered trauma an important factor in the development of the disease and coined the term "listhesis navicularis" to describe the displacement of the bone fragments after their fragmentation. Other synonyms, such as "adult tarsal scaphoiditis" or "bipartite navicular bone," have been used with less historical importance[13].

The prevalence and incidence of the disease remain unknown. It is more common in females, in the proportion of at least 2:1, reaching up to 9:1[2,3,5,6,12,14-23]. Bilateralism is more frequent than unilateralism[2,5,6,12,14,18,19,21,22]. It usually affects individuals between the fourth and sixth decades of life[2,5,6,12,14,15,16,19,21-25], although Maceira and Rochera find patients between 13 and 91 years of age, with a mean of 47.6 years at the time of diagnosis[3]. Doyle et al.[7] present a series of 12 cases[7], where a 14-year-old case was described, showing that although adolescents can be affected, it is an exception to the rule.

Still, in epidemiology, WMD affects patients with high body mass indexes[2,5,6,11]. Fornaciari et al.[26] report a mean body mass index of 29.6 kg/m^2, with a mean of 27 kg/m^2[14].

In the study by Molina et al.[27], it was found that obese patients with MWD presented unsatisfactory functional results, with reduced levels of quality of life. Although statistical significance was only in the SF-12 score, both in the physical and mental domains, this suggests that the trend of the patient's nutritional aspect warrants further observation and study.

In 2004, Maceira and Rochera[3] presented the largest case series in the literature, including 121 patients (191 feet), and proposed the cause of the disease as the combination of delayed navicular ossification—mainly due to a nutritional deficiency associated with intense environmental stress, such as wars and extreme poverty or the presence of endocrinopathies—with the abnormal distribution of tarsal weight-bearing compressing the navicular lateral portion by the talus head against the lateral cuneiform. This condition is associated with the subtalar joint varus and may be associated with the presence of a short first metatarsal that can lead to insufficiency of the first radius and abnormal lateralization of forces during gait overloading the second radius and the navicular lateral portion[2,6,12,14,22,28].

The navicular is the last tarsal bone to ossify, between two years in girls and four years in boys, and a failure in ossification can lead to higher shearing forces at the lateral cuneiform level[2].

The navicular is perfused by two arteries. The dorsalis pedis supplies the dorsal and lateral face of the bone, while the medial plantar artery supplies the plantar face of the navicular. The arterial supply has a circumferential pattern resulting in a centripetal that has a decreased blood supply, which may further reduce with age and may develop into osteonecrosis of the central third of the navicular or stress fractures[12,21], but not of its lateral portion as occurs in MWD[2,6,29].

Considered the cornerstone of the medial column of the foot, the navicular bone contributes to the integrity of the medial and transverse longitudinal arches of the foot. When fragmentation of the dorsolateral portion occurs with navicular collapse, progressive deformity and malalignment of the midfoot and hindfoot are installed, since any lateral displacement of the compression forces in the navicular can lead to greater flattening and bone fragmentation. With its collapse, there is secondary lateral displacement of the talus head and the consequent hindfoot varus[30]. With the advance of the disease, more collapse and fragmentation of the navicular result in the direct articulation of the talus with the lateral cuneiforms, creating sufficient space to allow plantar flexion of the talus head and, consequently, the paradoxical varus planus foot[2,3,12,21,30].

Hetsroni et al.[15] evaluated the distribution of plantar pressure in patients with MWD, demonstrating an increase in midfoot pressure, especially in the most lateral portion, associated with a reduction in toe pressure[3,15]. This pattern may contribute to the notable phenomenon of patients with MWD not developing hallux valgus[3,29],. Additionally, it appears to reflect an attempt by the plantar fascia to compensate for midfoot collapse through a realignment mechanism involving toe dorsiflexion[15].

Over the last century, other etiological possibilities have been proposed, such as trauma, congenital dysplasia, osteonecrosis associated with autoimmune conditions such as rheumatic diseases, systemic metabolic diseases such as diabetes, smoking, use of corticosteroids, alcohol, hematological diseases and abnormal evolution of Köhler disease[2,3,5,12].

The differential diagnosis involves Köhler disease, although it is unilateral in 75% to 80% of cases, affecting mainly male patients aged three to seven years, and being a self-limited pathology. In contrast, MWD is more often bilateral, affecting substantially more females and having a more dramatic evolution with progressive pain and deformity[2,5,21,31,32].

Secondary navicular osteonecrosis, post-traumatic, either by direct trauma, stress fracture, or pathological, that is, associated with diseases such as rheumatoid arthritis, systemic lupus erythematosus, or renal failure, usually causes unilateral involvement and systemic changes compatible with the underlying pathology[33]. Charcot arthropathy, on the other hand, is associated with an insensitive foot, usually due to peripheral neuropathy, especially in patients with Diabetes Mellitus[2].

Several pathologies can evolve into acquired flatfeet, such as progressive collapsing foot deformity, trauma, tarsal coalition, and neurological diseases, among others that, in general, occur with valgus flatfeet, not varus or neutral as occurs in MWD. Rheumatic diseases can evolve in some cases, with paradoxical flatfoot being an important differential diagnosis[8].

Tan et al. describe a single case with histology compatible with osteonecrosis[31]. Subsequently, this histological finding was observed by Singh and Ferrero in 2014, in a case of navicular necrosis associated with Mee lines (striated leukonychia) in the nails of the first and second toes affected, generating the hypothesis of temporary arterial occlusion; however, the histology compatible with navicular osteonecrosis was not evidenced in any other study in the literature[34], although another study concluded that the MRI findings are compatible, but not specific for osteonecrosis[35].

Histological studies found degenerative and reactive changes in bone[14] and navicular cartilage[36], as well as reductions of bone trabeculate, medullary fibrosis, and degenerative changes in the anatomopathological study described by Viladot et al.[37].

Mohiuddin et al.[6] propose that MWD is a sequelae of undiagnosed or underdiagnosed navicular stress fractures with the hypothesis that the central third of the navicular (hypovascular) is subjected to maximum shear stresses[6]. However, this theory does not explain the fragmentation of the lateral third, and there are no reports of MWD complicating navicular stress fractures[2].

Although Maceira and Rochera[3] and Monteagudo and Maceira[28] suggest the participation of environmental and social factors as predisposing, Doyle et al.[7] did not identify them in the etiopathogenesis.

The disease pathogenesis remains uncertain. Maceira and Rochera[3] suggest the delay in ossification is associated with abnormal forces distributed through the foot as prerequisites of the disease. Thus, we have a chondral structure more vulnerable to plastic deformity, leading to a deformed navicular bone. The delay in ossification may be due to extrinsic nutritional deficit (malnutrition, low socioeconomic status) or intrinsic (endocrinopathies, gastrointestinal diseases that interfere with nutrient absorption)[3,19,28].

In addition to the delay in ossification, there must be an excessive compression force on the lateral half of the navicular, between the talus head and the cuneiform, which may occur due to the primary varus of the subtalar joint, shortening of the first radius due to brachymetarsis (congenital or acquired) of the first metatarsal or deformities such as mild or undiagnosed congenital clubfoot. The hypermobility of the first radius also leads to lateralization of the load forces during gait overloading the second radius and the most lateral portion of the navicular[3,6,28].

Normally, the axial forces with the foot in plantar flexion transit through the first and second metatarsal-cuneiform joints, moving from the medial to the lateral half of the navicular that then suffers the pressure of the talar head.

However, the forces from the second metatarsal and intermediate cuneiform undergo less resistance, generating a maximum stress zone in the central third of the navicular, lateral to the center of the talar head. This area also has less vascular supply, which can generate stress fractures and consequent bone fragmentation, especially in the dorsolateral region of the navicular[2,3,6,28].

As the condition evolves, a space is created that takes the talus head to a plantar flexed position, clinically generating the paradoxical flatfoot in which the calcaneus assumes the stick position while the medialization of the cuboid occurs and the retroversion of the fibula in relation to the tibia with consequent external ankle rotation[3,6].

Although paradoxical flatfoot is the classic clinical manifestation associated with MWD, this deformity may arise as a result of other diseases not related to WMD or the most prevalent congenital deformities[38].

Initially, the clinical symptoms consist of chronic mid- and hindfoot, dorso-medial edema, and, in the most advanced stages, the paradoxical flatfoot. Secondary to the hindfoot varus, external tibial torsion occurs, generating anterior knee pain and later arthrosis[3,12,30]. It should be noted that there are reports of MWD with neutral calcaneus[23] or even some cases with valgus flatfoot, according to five cases included in the Haller et al. series[35] although the paradoxical flatfoot is the classic finding of the disease, it is not, however, a pathognomonic finding, according to Aebi et al.[38], which draw attention when finding varus flatfoot without associated MWD. Although Welck et al.[19] reinforce the obligation of the hindfoot varus to establish the MWD, Wong-Chung et al.[22] demonstrated through radiographic goniometry (talocalcaneal angle in AP incidence (Kite), talo-first metatarsal angle (Méary) and calcaneal moment-arm (Saltzman), obtained in the evaluation of 68 feet diagnosed with MWD the occurrence of hindfoot varus in only 33% of patients, determining that the finding of the paradoxical flatfoot is not a finding that defines the disease.

The diagnosis is clinical and radiographic. Maceira and Rocheira[3] propose a radiographic classification based on the lateral incidence in orthostasis. The degree of deformity is measured using the metatarsal talus - I angle (the angle formed between the talus long axis and the first metatarsal in the lateral incidence in orthostasis and whose normal value ranges from 0 to 10 degrees; above this value, the angular vertex pointing to the sole of the foot indicates the flatfoot). The stages are descriptive, and the symptomatology may not correspond to the degree of radiographic deformity. There are four stages described (Figure 1):

- Stage I: no radiographic change or, if it occurs, it is minimal; in nuclear magnetic resonance, there may be intraosseous edema, and a mild varus of the subtalar joint may occur;
- Stage II: a dorsal angle of the Meary angle occurs with dorsal subluxation of the talar head;
- Stage III: compression or division of the navicular with loss of the longitudinal arch, reduction of the space between the talar head and the cuneiforms, clinically the hindfoot is in varus, and the Meary angle is neutral;
- Stage IV: paradoxical plano foot occurs with equine hindfoot and plantar angulation of the Meary angle;
- Stage V: complete extrusion of the navicular with the formation of the talocuneiform joint.

Wong-Chung et al.[39], in 2023, analyzing 95 cases, suggested the categorization of WMD into three groups with similar radiographic characteristics to allow more accurate comparisons of the results of different forms of treatment. Unfortunately, neither the Maceira classification nor the classification proposed by Wong-Chung can inform or predict the prognosis of the different degrees of WMD. We hope that combining these two approaches, complemented by new studies, can help determine factors or parameters that correlate with the best therapeutic outcomes for these patients.

In addition to the radiographic findings already described, we can detect some others such as the formation of large dorsal osteophytes in the midfoot; navicular in the form of a "comma" or hourglass due to the collapse of its lateral half[6,12,17,19,35]; lateral or dorsolateral fragmentation of the navicular[3,6,12,17,19,35]**;** enlargement of the tarsal sinus indicating hindfoot supination [6,12,19,30]; reduction of the talocalcaneal angle[12,19,30], degenerative changes in the talar head; medialization of the cuboid in relation to the calcaneus (Figure 2); hypertrophy of the second metatarsal due, probably, to the lateralization of the compressive forces from the first to the second metatarsal, absence of the index plus metatarsal formula with a secondary shortening of the first metatarsal favored mainly by the internal rotation of the medial portion of the navicular[3,6,12,19,30,32].

Despite the clinical and radiographic criteria proposed by Maceira and Rochera[3], the diagnosis is challenging, partly due to the lack of knowledge of the disease and the wide variation of radiographic findings, generating some controversy in the literature, Ahmed et al.[40,41] describe seven adolescent patients using as inclusion criteria the radiographic presence of the navicular "in comma" and clinically of flatfoot with hindfoot in neutral or with mild valgus, a detail in disagreement with much of the literature, where the hindfoot of patients with MWD is in varus, in addition to being young and obese patients, while the literature mentions a very rare involvement in young people with low body mass index as emphasized by Myerson[42].

Weight-bearing computed tomography allows the evaluation of the relationship between the midfoot and the hindfoot, allowing a dynamic analysis of the regions involved and the deformity under the effect of the weight-bearing on the foot involved, playing an important role in the reconstruction planning[19]; however, it is not an easily accessible exam in the Brazilian reality, and it is possible to rely on this resource in very few services at the moment. Computed tomography, especially with three-dimensional reconstruction, has its place in preoperative planning, allowing the verification of osteoarthritis in adjacent joints, analysis of possible fracture lines, measurement of the shortening of the medial column, and evaluation of bone quality and stock[5,19,21,25]. Mayich[25],

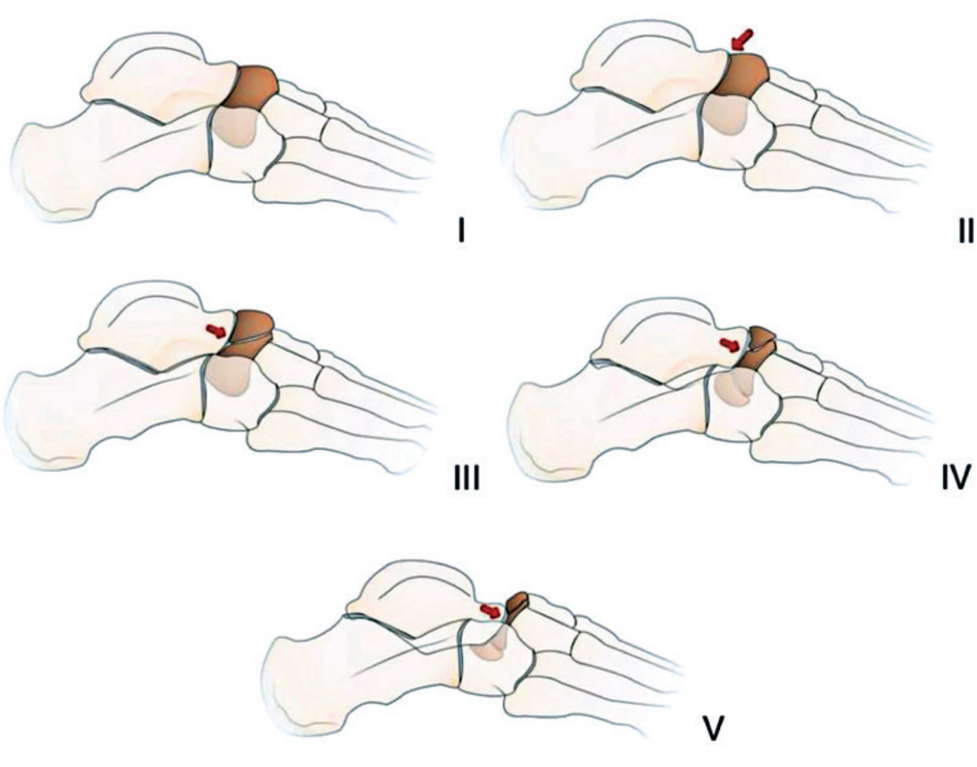

Figure 1. Classification of Maceira (authors' collection).

based on the findings of computed tomography, adds the presence of subtalar arthrosis in stage IV of the Maceira and Rochera classification[3].

Nuclear magnetic resonance aids in the differential diagnosis of conditions like stress fractures, osteonecrosis, or infection. It also enables the evaluation of soft tissues, such as the spring ligament and posterior tibial tendon, and is highly sensitive in detecting bone edema, early signs of perinavicular arthrosis, and potential hidden stress fractures[12,21,30,33,35].

Regarding treatment, many authors initially propose non-surgical treatment for periods ranging from 2 to 60 months[2,3], during which non-hormonal anti-inflammatory drugs, support or accommodation orthoses[41], activity restriction, or even a cast immobilization without weight-bearing[5,12,14,25] are used.

For the success of the non-surgical treatment, Mayich[25] alerts to the importance of six factors: (1) patient guidance for understanding the pathology and engagement with the proposed treatment; (2) modification of physical activities, replacing high-impact activities on the midfoot by swimming or cycling, for example; (3) reduction of body weight to minimize overload in the midfoot; (4) modification of footwear with the use of a convex-rigid sole (blotter); (5) use of semi-rigid insoles with support of the medial arch custom-made to fit the patient; (6) consider rigid orthoses for patients who are not candidates for surgery and have not responded to the other measures.

In general, the purpose of orthoses treatment and alteration of shoes in conservative treatment is to reduce the mobility of the midfoot[30] with the discharge of the talonavicular joint in the phase of the detachment of the calcaneus during gait. Thus, Fernández de Retana et al.[43] recommend semi-rigid insoles supporting the medial longitudinal arch, with satisfactory evolution in many cases. Perisano et al.[21], as well as Monteagudo and Maceira[28] and Hermena and Francis[30], mention the possibility of using insoles with a valgus wedge in the hindfoot, in addition to the rigid support of the medial arch with symptomatic improvement in about 80% of the cases. Ruiz-Escobar et al.[4] use insoles with total pronator wedge, that is, from the hindfoot to the forefoot in the retrocapital region of the fourth and fifth metatarsals, correcting, in addition to the hindfoot varus, the relative supination of the forefoot, with good results in ten feet described, avoiding surgical procedures in seven feet. In more advanced cases with talonavicular arthrosis, rigid orthoses can be important in controlling peritalal movement and generating symptomatic relief[2].

Many studies, however, suggest little response to non-surgical treatment[12,19,26,31,44].

According to most of the literature, the severity of the symptoms and not the deformity determines the surgical indication, although most surgical patients are in stages III, IV, or V. Surgical procedures aim to obtain a plantigrade foot, with pain relief, restoration of the medial longitudinal arch and the plantar cavus, as well as the Meary angle[5,6,12,25,30,45].

Liu et al.[23] highlight the importance of using computed tomography and nuclear magnetic resonance imaging in surgical planning, especially in Maceira stage IV, allowing the identification of adjacent joint arthrosis, and thus ensuring

Figure 2. Patient 1, classic findings in the right foot, navicular in "comma" with tapering of the lateral portion, index minus, and medialization of the cuboid.

the best procedure for each case. Wong-Chung et al.[22] use radioisotope emission tomography, the so-called Single Photon Emission Computed Tomography (SPECT-TC), to guide the surgical indication.

Arthrodesis aims to achieve the goals of surgical treatment on feet with painful and degenerative joints, while reconstruction procedures aim to achieve goals by realigning the axes of the foot in joints without degenerative arthropathy.

There are several proposed surgical procedures:

- Percutaneous decompression of the navicular[46];
- Isolated talonavicular arthrodesis[16,26,29,47-50];
- Osteosynthesis of the navicular[33];
- First ray arthrodesis (talo-navicular-cuneiform)[20,24,43,51-53];
- Double arthrodesis (talonavicular and calcaneal cuboid)[23];
- Open or arthroscopic triple arthrodesis[16,20,54];
- Allograft interposition arthrodesis[31];
- Calcaneus valgus osteotomy[3,45,55];
- Resection of the diseased navicular bone and reconstruction of the medial column with femoral head bone graft[31];
- Resection of the diseased navicular bone and filling the gap with an autologous spongy graft from the iliac crest[44];
- Associated techniques (talonavicular or talonavicular-cuneiform arthrodesis and calcaneus osteotomy)[43,49].

All these procedures, in general, require the use of autologous, allogeneic, structural, or morselized grafting, depending on the case and the surgeon's preference, with good results reported[6,16,24,36,43,44,51,56].

All techniques can also be associated with calcaneus tendon elongation[6,43] and/or calcaneus valgus osteotomy if significant residual varus is detected[3,28,49].

Isolated talonavicular arthrodesis is a good option in cases where the subtalar and calcaneal-cuboid joints are preserved[26,29,57] (Figure 3). However, this procedure has the highest rates of consolidation failure [43,51], although Cao et al.[57] reported a 100% success rate in their series of 16 patients who used 4.0 mm cannulated screws to fix the fusion area. Samim et al.[12] warn of the high risk of pseudarthrosis in isolated talonavicular arthrodesis since the navicular-cuneiform joint is not addressed.

Furthermore, triple arthrodesis does not improve the symptoms resulting from changes in the navicular-cuneiform joint and may require the extension of arthrodesis to the medial cuneiform[7,12,20] (Figure 4). The procedure can be performed openly or arthroscopically, according to the description by Lui et al.[54], highlighting that the cases submitted to this technique did not present significant deformity or signs of navicular-cuneiform arthrosis.

In the study conducted by de Alcântara Jones et al.[58] in 2022, a group of 26 patients (31 feet) were followed over a 19-year period (1994-2013). During this follow-up, there was

Figure 3. Patient 2 underwent bilateral isolated arthrodesis with consolidation.

a significant incidence of pseudarthrosis in the procedures of talonavicular arthrodesis and triple arthrodesis of the foot as a treatment for sequelae of MWD, reaching about 30%. Despite this failure rate in consolidation, the improvement in pain intensity in most of the cases analyzed was clear, in addition to similar clinical-functional results with autologous tricortical grafting of the iliac bone and the navicular bone itself as a bone source.

Osteosynthesis of the navicular, in turn, is rarely possible due to the loss of bone stock in the more advanced stages of the disease[5,43].

Talo-navicular-cuneiform arthrodesis has the best results in the studies[12,21], and can be performed with low-profile screws or plates, with allograft[31] or autograft[43], or associated with complementary osteotomy in the talonavicular with base resection wedge to elevate the plantar arch as proposed by Cao et al[51].

According to Zhang et al.[20], triple and talo-navicular-cuneiform arthrodesis provide excellent results, and it is important that, even if the surgeon opts for triple arthrodesis, the navicular-cuneiform joint should be included in the fusion if it has degenerative changes.

Sometimes the reduction of the talonavicular joint can be hampered by the large ligament retraction in the subtalar, requiring the release of this joint through the tarsal sinus[36].

The isolated calcaneal valgus osteotomy has been used with good and excellent results in 15 of the 18 patients in the Monteagudo and Maceira series[28]. Li et al.[45] report the absence of poor results in 14 feet treated by gliding osteotomy associated with calcaneal lateral wedge resection, even in more advanced stages, that is, Maceira III, IV, and V, with a mean follow-up of 3.7 years (ranging from 1 to 8.5 years) without the need for complementary surgeries.

As for the synthesis material to be used in the fixation of arthrodesis, the choice depends directly on the amount of bone stock present, so in the stages of Maceira II and III, where there is more favorable bone stock, except, in the lateral portion of the navicular, the screws and staples provide a good fixation, while in stages IV and V, with greater bone involvement, the use of more rigid synthesis material is indicated, often requiring the use of structural bone grafting, and it may be unnecessary to use synthesis if the graft is placed under pressure that provides the ideal stability[43]. According to Kitaura et al.[52], it is preferable to use rigid plates with a robust profile to perform talo-navicular-cuneiform arthrodesis as a way to improve the consolidation rate and the outcome of patients with this type of indication.

Tan et al.[31] describe in their study the debridement with excision of the navicular and reconstruction of the medial column of the foot using remodeled femoral head allograft, whose advantage would be the reduction of local and general morbidity by dispensing with the collection of autologous graft. However, they highlight the possibility of osteolysis and absorption. On the other hand, Levinson et al.[59], using a vascularized free bone graft from the medial femoral condyle to reconstruct the medial column of the foot, showed excellent evolution after an 18-month follow-up.

Figure 4. Patient 3, fixed talo-navicular-cuneiform arthrodesis with locked plate associated with cannulated screws. Consolidated arthrodesis.

For all the procedures mentioned here, it is recommended to use immobilization without weight-bearing for a period ranging from 8 to 12 weeks[(6)].

There are few reports of the early stages of MWD treated with percutaneous navicular decompression[(15,29,46)]. Janositz et al.[(46)] describe the case of an 18-year-old patient who was followed for eight years after surgery and who evolved with a complete remodeling of the worked area, which could be proven by MRI studies. Tosun et al.[(44)] reported resection by curettage of the affected bone and filling the navicular failure with an autologous spongy graft from the iliac crest. However, identifying the disease in its early stages is rare, leaving little room for this technique to be used[(12,30)].

Calcaneus osteotomy by sliding or wedge resection is indicated in the presence of a significant varus to adjust the load axis of the foot during gait. This procedure helps restructure the medial arch and lateralize the calcaneus after osteotomy[(2,40,45)]. The procedure can be performed alone or associated with joint fusions[(45,49)].

Some studies propose decompression through serial drilling or simple resection of the affected area in Maceira stages I or II[(46)], isolated talonavicular arthrodesis in moderate III and IV stages, and talo-navicular-cuneiform arthrodesis, double or triple arthrodesis in stage V[(29)]. Mayich[(25)] recommends talo-navicular-cuneiform arthrodesis already in stage III and triple arthrodesis from stage IV (Figure 5).

Molina et al.[(27)] reported a significantly favorable difference in surgical treatment considering the evaluation of quality of life, agreeing with studies in the literature[(2,45)]. Regarding age, Harnoongroj et al.[(60)] concluded that young patients have worse results with non-surgical treatment than those submitted to surgical procedures.

Molina et al.[(27)] study is the only one in the literature that draws attention to the deterioration of quality of life, especially in obese patients, regardless of other factors such as sex, race, age, and socioeconomic conditions, alerting to the need for multidisciplinary monitoring, including nutrology and clinical specialties to control any metabolic and endocrinological disorders that may result in increased BMI.

Finally, an accurate understanding and diagnosis are essential to enable more population studies that can provide a comprehensive understanding of the disease's progression. This will help identify the most effective treatment methods to ensure optimal quality of life and foot function for patients, particularly in light of the rising prevalence of obesity in Brazil and worldwide.

Thus, it is concluded that WMD is a rare and complex disease, and its etiological characteristics and treatment, in the most varied forms, still lack consensus in the literature. Therefore, the treatment to be followed must be individualized for each foot affected, respecting the context and characteristics of each patient.

The "State of the art" on this pathology contributes to the diagnostic elucidation and the determination of the best way to approach the carrier of this *sui generis* pathology.

Figure 5. Patient 4, with signs of involvement of all peri-navicular joints preoperatively, underwent triple arthrodesis.

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Systematic Review

Opioid consumption following foot and ankle surgery: a systematic review

Christian DeMaio[1], Robert Nayfa[1], Ty Reasnor[1], Jake Fox[2], Zackary Burrow[3], Samuel Thompson[4], Amgad Haleem[5,6]

1. Department of Orthopedic Surgery and Rehabilitation, College of Medicine, University of Oklahoma Health Sciences Center, Oklahoma City, Oklahoma, USA.
2. Vanderbilt University Medical Center, Nashville, Tennessee, USA.
3. Advanced Orthopedics of Oklahoma, Tulsa, Oklahoma, USA.
4. Columbia Orthopaedic Group, Columbia, Missouri, USA.
5. Department of Orthopaedic Surgery, Harvard Medical School, Massachusetts General Hospital, Boston, Massachusetts, USA.
6. Department of Orthopedic Surgery, Kasr Al-Ainy Hospitals and College of Medicine, Cairo University, Cairo, Egypt.

Abstract

Objective: Systematically review studies characterizing postoperative opioid consumption in patients submitted to foot and ankle surgery to identify trends in opioid consumption among regions of procedures (forefoot, midfoot, hindfoot/ankle) and ultimately create prescribing guidelines that treat patient's pain adequately while limiting leftover pills.

Methods: A systematic review was performed following the Meta-analysis of Observational Studies in Epidemiology (MOOSE) guidelines. Retrospective and prospective observational cohort studies that reported mean opioid consumption following foot and ankle surgery were included, as well as data from our institution that fit the review's parameters. Studies that did not report this data or reported patients receiving alternative surgical techniques were excluded. The risk of bias in non-randomized studies – of exposure (ROBINS-E) tool and the Methodological index for non-randomized studies (MINORS) criteria were used to assess bias and study quality, respectively.

Results: Three hundred ninety-five articles were identified, and six studies, including our institution's, met inclusion criteria. Reported data from 2,445 patients were synthesized to show opioid consumption overall, by region of surgery, and by invasiveness of procedure. Four of five studies found significantly higher opioid use postoperatively in patients submitted to hindfoot/ankle surgery, and two of five studies found significantly higher consumption among those submitted to bony foot and ankle surgery.

Conclusion: Prescribing physicians must approach foot and ankle patients on a case-by-case basis to ensure adequate pain management while mitigating excess opioid risk. For prescriptions of 5 mg oxycodone pills, we recommend 15-, 20-, and 25-pill prescriptions for patients submitted to forefoot, midfoot, and hindfoot/ankle surgery.

Level of Evidence I; Systematic review.

Keywords: Opioid; Epidemic; Consumption; Foot/surgery; Ankle/surgery.

Introduction

The opioid epidemic has risen to the national forefront as rates of drug overdose deaths continue to climb[1,2]. The overuse and over-prescription of narcotic medications began in the 1990s when pain was declared the "fifth vital sign"[3]. An increased emphasis on patient satisfaction scores and a perceived "under-treatment" of pain resulted in a rapid increase in the quantity of narcotics prescribed in the United States[3,4]. This increased opioid utilization was paralleled by a rise in opioid drug poisoning mortality rates, which increased by an average of 18.1% per year from 1990 to 2002[5,6]. Currently, opioid abuse continues to claim lives at an alarming rate. In 2016, opioid overdoses killed more Americans than motor vehicle collisions or gun violence[7,8].

Initial narcotic prescriptions have been shown to play a key role in the opioid epidemic, and opioid-naïve patients are at

Study performed at the Department of Orthopedic Surgery and Rehabilitation, University of Oklahoma Health Sciences Center, Oklahoma City, USA.

Correspondence: Amgad Haleem. 55 Fruit St, Boston, MA 02114, USA. **Email:** haleem@kasralainy.edu.eg. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** April 27, 2024. **Date accepted:** July 17, 2024. **Online:** August 30, 2024..

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an increased risk of chronic opioid use following surgery[9-11]. Nearly 9% of cases of opioid dependence in previously opioid-naïve patients are attributed to legal prescriptions provided following foot and ankle surgery[12]. Orthopedic surgeons are among the highest prescribers of opioids in the United States, and much attention has been drawn recently to the need for safer postoperative narcotic prescribing practices[13-16].

Several recent studies across multiple orthopedic subspecialties have evaluated prescribing patterns and postoperative narcotic usage, including within foot and ankle surgery, with no consensus or general prescribing guidelines for providers[17-24].

The objective of this study is to perform a systematic review to examine the opioid pill consumption of patients following foot and ankle surgery and to provide more data-driven guidelines with more statistical power for physicians prescribing opioid analgesics broken down into three categories based on region of procedure (forefoot, midfoot, hindfoot/ankle). To our knowledge, this study is the first to provide generalized prescribing guidelines following foot and ankle surgery based on anatomic region.

Methods

Data sources and search

A systematic review was performed following the Meta-analysis of Observational Studies in Epidemiology (MOOSE) criteria. The following databases were searched: PubMed, EBSCOHost, and Ovid MEDLINE. The search terms “opioid” and “foot and ankle surgery” with the Boolean operator (AND) were used with each search engine, yielding results from eleven databases (Figure 1). All search results were compiled into Microsoft Excel and were independently reviewed by three reviewers.

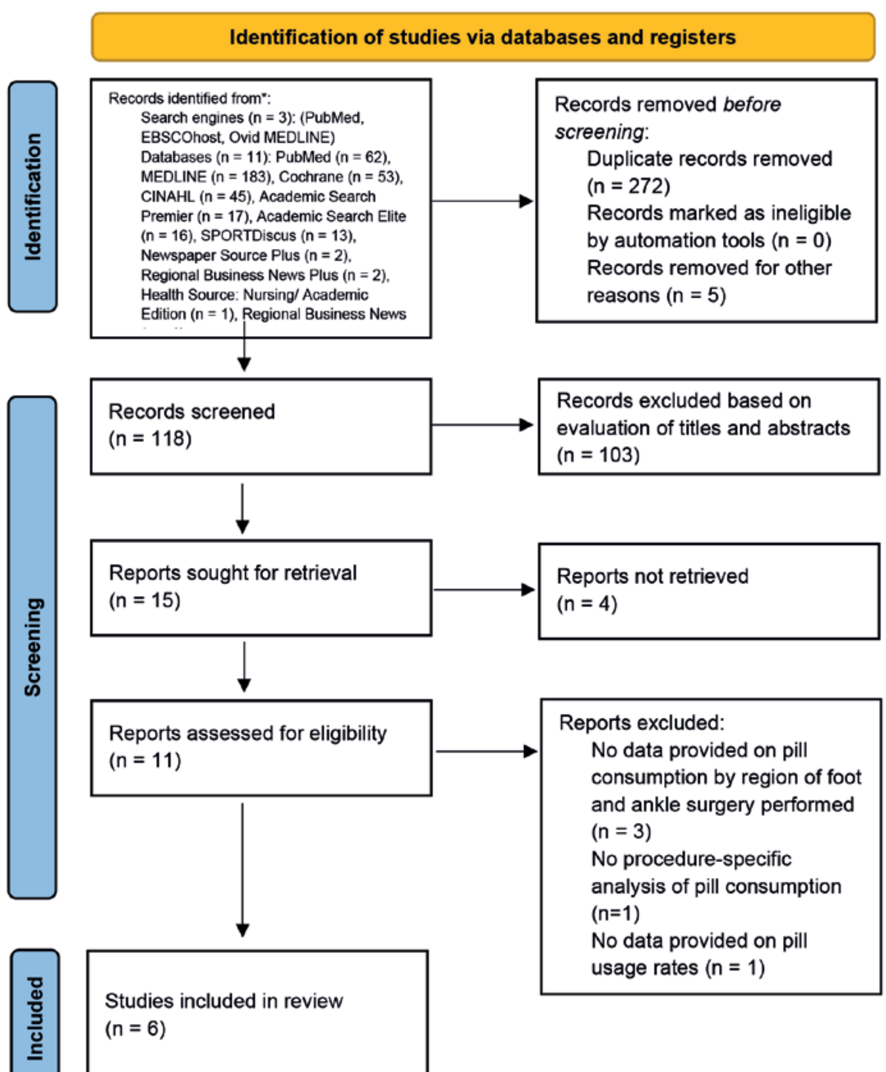

Figure 1. PRISMA flowchart showing the identification and inclusion of studies.

Inclusion criteria

Retrospective case series, retrospective cohort, and prospective observational studies that reported opioid consumption data among patients who recently were submitted to foot and ankle surgery were included. To be included, studies needed to report a breakdown of the surgical procedures that the patients were submitted to, as well as a measure of postoperative opioid consumption. Opioid prescriptions, whether already reported as such or as morphine milligram equivalent (MME), were standardized to the unit of one 5 mg oxycodone pill.

Exclusion criteria

Studies that did not report opioid consumption data after procedures from all regions of procedure (forefoot, midfoot, hindfoot/ankle), did not provide data on opioid usage, and only provided data on foot and ankle surgeries using percutaneous techniques were excluded. Also, a study comparing a higher vs. lower initial opioid prescription pill count due to its potential to affect the number of pills patients would have at their disposal postoperatively was excluded.

Unpublished study from authors' institution[25]

The study was approved by the Institutional Review Board, and then patients submitted to outpatient foot and ankle surgery were prospectively enrolled at a single academic medical center between March 2018 and April 2019 to determine how many opioid pills were consumed after surgery. A total of 78 patients were included consecutively. Eligible participants were at least 18 years of age, English-speaking, and willing to complete postoperative surveys via phone calls and follow-up visits with the authors. Exclusion criteria included narcotic use within one month before surgery (other than prescriptions provided at emergency department visits for acute fractures), past chronic narcotic use, history of chronic pain requiring pain physician management, another fracture at any site, and current pregnancy.

Once written informed consent was obtained by the authors, a preoperative survey was conducted on the day of surgery to determine the visual analog scale (VAS) pain score and level of schooling completed. The authors reviewed demographic data, including age, sex, body mass index (BMI), and payer status. Electronic medical records were used to identify the primary procedure performed, the region of procedure (forefoot, midfoot, hindfoot/ankle), and whether a regional anesthetic block was utilized. The state Prescription Monitoring Program (PMP) database was utilized to identify opioid prescriptions filled up to 12 months before surgery and up to two months following surgery. The number of pills and MMEs prescribed was calculated. Patients were categorized as opiate exposed if they filled a single narcotic prescription up to 12 months before surgery.

Following surgery, prescriptions were written by both resident and attending physicians. Surgeons were instructed to follow their standard postoperative prescribing habits, with resident prescriptions verified by the attending physician. Prescription information was collected utilizing the state PMP database for all patients by the study's authors. Follow-up surveys were conducted via phone calls on postoperative days (POD) 5 and 10 and in-person at 2 and 6-week postoperative clinic visits to document VAS pain score, number of pills consumed, number of pills remaining, satisfaction with pain control, whether additional non-narcotic pain medication was being utilized, and reasoning for discontinuing narcotic usage if applicable. Patients were instructed to bring any remaining pills to their clinic visits to be counted for accuracy by research staff and discard remaining pills when no longer requiring opioid medications for pain control. Patients were included for analysis if at least 2/4 surveys had been completed.

Narcotic consumption was defined as the number of opioid pills remaining at the last available visit. Pill utilization was calculated as the percentage of pills remaining. (For example, if 2/10 pills remained, the utilization rate was 80%). Due to small sample sizes in the midfoot and forefoot regions, proportions were compared between regions using Fisher's exact test. The Kruskal-Wallis test was used for continuous measures. A paired t-test was used to test the change in pain level from the preoperative visit to the last available visit. Linear regression modeling was used to determine if any demographic, baseline clinical characteristics, over-the-counter medication use, or previous opiate exposure was associated with total narcotic consumption.

Data extraction for systematic review

Three reviewers extracted data from the studies that met the inclusion criteria. Data collected from the studies included year, study design, location, patients enrolled, mean number of oxycodone 5 mg pill equivalents prescribed, mean number of pills consumed postoperatively, pill utilization rates, number of pills left over at the end of the study, mean or median number of pills consumed based on region of patient's surgery, and mean or median number of pills consumed based on bony vs. soft tissue procedures of the foot and ankle.

Bias and quality assessment

The included studies were assessed for bias using the Risk of Bias in Non-randomized Studies-of Exposures (ROBINS-E) tool (Figure 2)[26]. Additionally, the Methodological Index for Non-Randomized Studies (MINORS) was used to assess study quality (Table 1)[27].

Results

The search identified 395 studies. Three reviewers independently evaluated 119 non-duplicate studies. One hundred two studies were excluded based on irrelevant titles and abstracts. Seventeen full-text studies were retrieved, with five fulfilling inclusion criteria. Of the included studies, two were retrospective case series, two were prospective observational

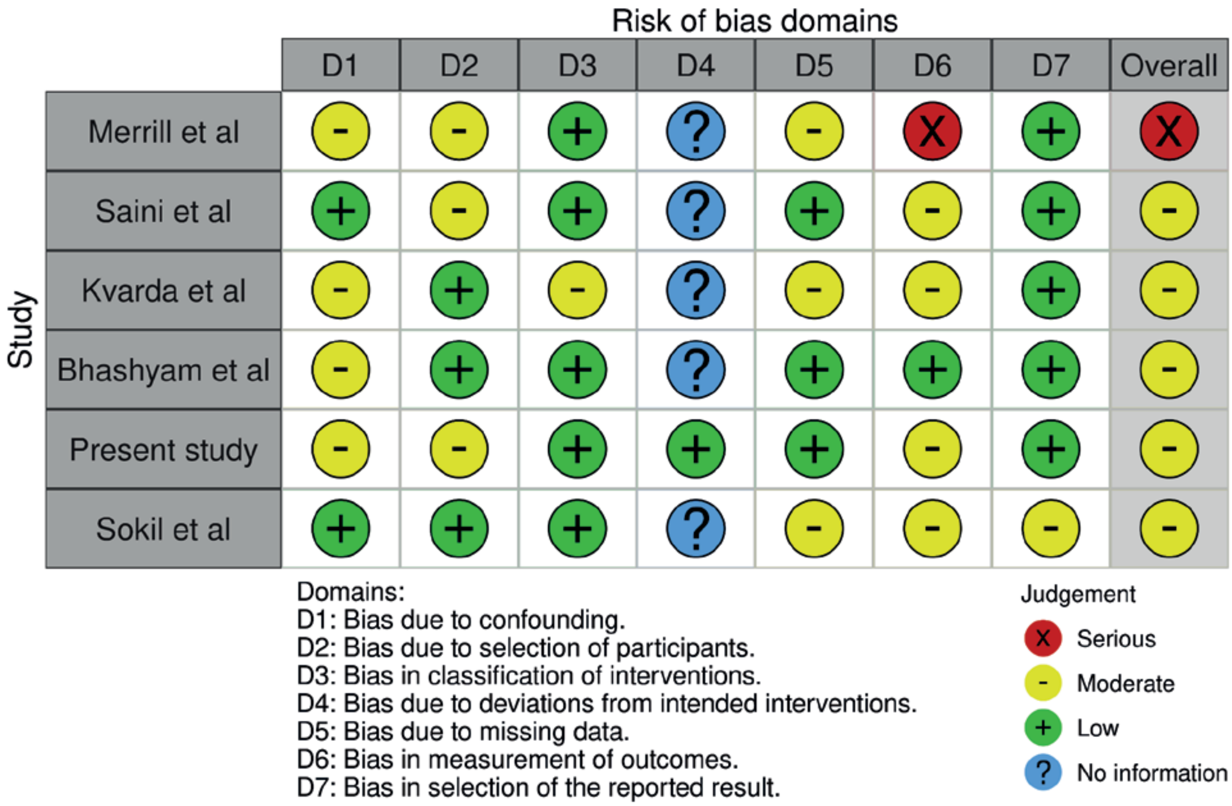

Figure 2. ROBINS-E tool results for the six included studies.

Table 1. MINORS scores for the six included studies

Study	A clearly stated aim	Inclusion of consecutive patients	Prospective collection of data	Endpoint appropriate to the aim of the study	Unbiased assessment of the study endpoint	Follow-up period appropriate to the aim of the study	Loss of follow-up less than 5%	Prospective calculation of the study size	Total MINORS score
Merrill et al.	2	1	2	2	2	2	1	2	14
Saini et al.	2	1	2	2	2	2	1	2	14
Kvarda et al.	2	2	2	2	2	2	1	2	15
Bhashyam et al.	2	2	2	2	2	2	2	2	16
Present study	2	2	2	2	2	2	2	2	16
Sokil et al.	2	1	1	1	2	2	2	2	13

cohort studies, and one was a retrospective follow-up of a prospective cohort study. Along with the five studies that met inclusion criteria, we have included an unpublished prospective observational cohort study conducted at our institution that was presented at the AOFAS Annual Meeting[25] to introduce additional data relevant to the subject at hand. Study characteristics can be found in Table 2. Contact with the authors of the included studies was attempted via email.

Primary outcomes

Opioid consumption data divided by region of foot and ankle surgery was the primary focus of this study (Table 3). Merrill et al. reported this data using the mean pills consumed but divided each region of surgery based on short-acting vs. long-acting opioids[22]. Meanwhile, Bhashyam et al. reported mean pills consumed by region of surgery but also further divided the groups by bony vs. non-bony procedures[17].

Table 2. Descriptive summary of the six included studies in the systematic review

	Year	Location and design	Age, years (mean)	Size (n)	Primary outcomes measured	Secondary outcomes measured
Merrill et al.	2018	Falls Church, VA, retrospective case series	53.1	132	Anatomic region of foot and ankle procedure and postoperative opioid pill consumption	Opioid pill consumption among bony vs. nonbony procedures of the foot and ankle, association between short-acting and long-acting opioids prescribed, and willingness to surrender leftover pills
Saini et al.	2018	Philadelphia, PA, prospective observational cohort	49	988	Opioid pill consumption patterns among patients submitted to foot and ankle surgery and the resultant over-prescription of opioids in this population	Risk factors for higher opioid consumption
Kvarda et al.	2019	Boston, MA, retrospective case series	50	244	Identify risk factors for higher opioid pill consumption in patients submitted to foot and ankle surgery and determine the rate of pill consumption	Estimate number of unused opioid pills following the conclusion of the study
Bhashyam et al.	2019	Boston, MA, prospective observational cohort	50.5	303	Opioid pill consumption based on anatomic region of surgery and between bony vs. non-bony procedures of the foot and ankle	Use findings to guide the creation of new prescribing algorithms based on the primary outcomes of the study
Present study	2019	Oklahoma City, OK, prospective observational cohort	45.2	78	Evaluate opioid pill consumption following foot and ankle surgery and identify risk factors for increased pill consumption	Estimate rate of patients with unused opioid pills at the conclusion of the study
Sokil et al.	2020	Philadelphia, PA, retrospective follow-up of prospective cohort	50.9	700	Determine the relationship between patient-reported pain tolerance and opioid pill consumption following foot and ankle surgery	Identify risk factors for higher opioid pill consumption based on demographic data and procedure characteristics

Table 3. Analysis of results of the included studies by anatomic region

	Forefoot, mean pills consumed	Midfoot, mean pills consumed	Hindfoot, mean pills consumed	Ankle, mean pills consumed	p-value
Merrill et al., short-acting opioids	18.7	24.5	21.7	b	0.356
Merrill et al., long-acting opioids	4.5	5.2	8.4^a	b	*0.0466*
Saini et al.	16*	18*	22*^a	b	*<0.001*
Kvarda et al.	-	-	-	-	-
Bhashyam et al., bony procedures	17	26.1	34.7^a	28.4	*<0.001*
Bhashyam et al., non-bony procedures	10	13.8	10.6	14.1	-
Present study	11*	17.5*	40*	b	0.0835
Sokil et al.	-	-	-	-	-

*= only median reported, a= statistically significant, b= data included in hindfoot category.

While Kvarda et al. provided useful data for this review, opioid consumption data was reported in categories made by the authors based on the invasiveness of the procedure rather than the anatomic region[21]. Sokil et al. reported the number of procedures performed per region of foot and ankle in their study; however, the mean pill consumption among each region was not reported[24]. Saini et al. reported measures of opioid consumption among regions of foot and ankle surgery using the median instead of the mean[23].

Secondary outcomes

Also of interest to this review were data on overall opioid consumption within foot and ankle surgery (Figure 3), as well as opioid consumption among bony vs. non-bony procedures of the foot and ankle (Table 4). Sokil et al. and Kvarda et al. did not report mean opioid pill consumption in bony and non-bony foot and ankle procedures, but both listed opioid pill consumption following bony procedures was significantly

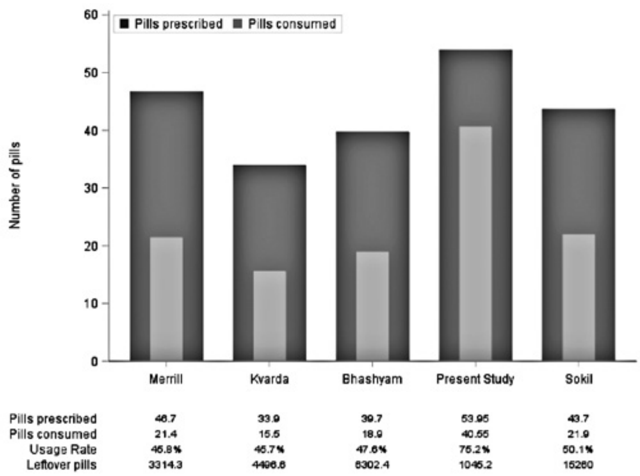

Figure 3. Pills prescribed vs. pills consumed in the included studies.

Table 4. Descriptive analysis of bony vs. non-bony procedures

	Bony procedures, mean pills consumed	Non-bony procedures, mean pills consumed	p-value
Merrill et al., short-acting opioids	21.6	19.7	0.491
Merrill et al., long-acting opioids	6.4	5	0.358
Saini et al.	20*	16*	0.069
Kvarda et al.	-	-	0.001
Bhashyam et al.	25	14	< 0.001
Present study	-	-	-
Sokil et al.	-	-	> 0.05

*= only median reported.

higher with associated p-values[21,24]. Saini et al. also used the median in reporting this measure[23]. The author's unpublished data did not investigate opioid consumption among bony vs. non-bony procedures.

Collection of opioid pill consumption data

Merrill et al. and Kvarda et al. used patient-reported counts of pill consumption[21-22]. In the unpublished study, patients were asked to complete a survey assessing the number of pills consumed and asked to bring the remaining pills to the clinic to be counted by a research team member for accuracy. Likewise, Saini et al., Bhashyam et al., and Sokil et al. reported that pill counts were verified by a member of their research team at the patient's first postoperative visits[17,23,24].

Risk factors

The included studies in this review also investigated any statistical relationship to demographic factors and factors pertaining to the patient's surgeries. In 4/6 studies, opioid consumption among patients submitted to hindfoot/ankle procedures was significantly higher compared to patients of the other two categories (Table 3)[17,22-24]. Half of the studies reported that patients submitted to bony procedures of the foot and ankle consumed a significantly higher number of opioid pills (Table 4)[17,21,23]; likewise, our unpublished data, along with two of the studies, found a statistically significant relationship between greater initial prescription amount and greater opioid consumption[21,24]. Less overall concordance among the studies was noted for statistical significance reported regarding higher opioid consumption and preoperative opioid use,[17,22] smoking status[21], younger age[17,24], traumatic surgery (versus elective)[21-22], male sex[17], higher BMI[21], and nerve block/catheter anesthesia[21,22]. Additionally, our unpublished data and Saini et al. noted that patients with higher preoperative VAS pain scores consumed more opioids[23].

Regression analyses

Out of the six studies, only Merrill et al. did not report using a regression model to investigate risk factors for increased opioid consumption but instead opted to use a t-test for continuous variable analysis and a chi-square test for frequency analysis[22]. Kvarda et al., Sokil et al., and our unpublished study all used bivariate regressions in identifying risk factors for increased opioid consumption among their patients, while Bhashyam et al. and Saini et al. utilized forward and backward, respectively, stepwise multivariable regressions to further investigate for patient-and procedure-related associations[17,21,23,24]. Lastly, Kvarda et al. also employed a multivariable regression model, which was the basis for a statistically significant difference between patient's opioid consumption following bony vs. non-bony procedures[21].

Prescription guidelines

Based on their mathematical model, Bhashyam et al. provided only opioid prescription guidelines divided into regions of surgery (forefoot, midfoot, hindfoot/ankle) and invasiveness of procedure (bony and non-bony)[17]. Kvarda et al. and Merrill et al. related that from their data, it seemed as though the prescriptions could have been cut in half and, generally, the patient's pain would have been treated adequately[21,22].

Discussion

Following foot and ankle surgery, it is generally apparent that opioid consumption increases from forefoot to midfoot to hindfoot/ankle procedures. Out of the four studies that reported opioid consumption in patients by region of surgery, three studies reported that patients submitted to hindfoot surgeries consumed significantly more opioids than patients in the other anatomic region[17,22,23]. Our study did not find a significant difference (p = 0.08) between regions of the foot, although there seemed to be an association between the number of pills consumed and the region of foot surgery. However, the lack of statistical significance may be due to the small sample size in the midfoot and forefoot regions. The higher opioid requirements for the hindfoot/ankle region were attributed to the greater VAS pain scores reported in this group both pre-and postoperatively and to the large number of ankle fractures included in this group. This finding encourages foot and ankle surgeons to consider prescribing fewer numbers of pills to patients submitted to forefoot and midfoot surgery compared to patients submitted to hindfoot/ankle surgery.

Half of the studies included in this review reported significantly greater opioid consumption among bony vs. non-bony procedures of the foot and ankle, with Saini et al. reporting a p-value of 0.069, which was low but did not meet statistical significance[17,21,23]. In addition, opioid prescription usage rates ranged from 45.7% to 75.8%. Other studies have also demonstrated a similar correlation between opioid prescription size and overall consumption[28-30]. A likely explanation for this finding in our study and others is that patients who are prescribed more analgesic medication by a physician may assume their pain needs will be greater than those who are prescribed fewer pills.

Several studies have been recently published on opioid prescribing patterns and patient consumption following foot and ankle surgery that were excluded from this study for reasons such as randomization of initial prescription quantity and not providing opioid consumption data following procedures of the forefoot, midfoot, hindfoot/ankle. Gupta et al. prospectively evaluated opioid utilization in 84 patients and reported that a mean of 55.5 pills were prescribed, but only 22.5 pills were consumed[18]. Rogero et al. found that younger age, higher preoperative VAS pain scores, and bony procedures were associated with higher opioid utilization[30].

Similar to the results published by Saini et al. and Kvarda et al., it was found that higher preoperative VAS pain scores and initial opioid prescription size were predictive of increased narcotic consumption[21,23]. Higher patient-reported pain scores have been previously linked to pain catastrophizing and increased postoperative analgesic requirements[31-32].

Contrary to the results of several other studies in this review, our study did not find a correlation between preoperative opioid use and postoperative narcotic consumption[33-35]. The most likely explanation for this finding is that our study was underpowered to identify a significant difference. Also, an association between regional anesthesia use and narcotic consumption was not found. Christensen et al. found that regional anesthesia use reduced postoperative opioid consumption in 622 patients following ankle fracture fixation[36]. Gupta et al. also found lower pain scores and decreased narcotic usage for patients who received regional anesthesia following outpatient foot and ankle surgery[18]. Again, we may have been underpowered to find a significant effect of regional anesthesia on opioid consumption. Our findings are also attributable to the fact that regional anesthesia was used significantly more often in the hindfoot/ankle group than in the midfoot and forefoot groups. The more frequent use of regional anesthetic for procedures found to be more painful (higher VAS pain scores) and associated with greater opioid consumption introduces selection bias when analyzing the effect of regional anesthesia.

Recently, high rates of persistent narcotic use have been demonstrated in the foot and ankle literature. Utilizing a United States insurance claims database, Finney et al. identified 36,562 patients submitted to surgical treatment for hallux valgus and determined that 6.2% of patients had new persistent opioid use, defined as fulfillment of a narcotic prescription between 91 and 180 days after surgery[37]. In a similar study, Gossett et al. reported new persistent opioid use in 8.8% of patients following open treatment of ankle fractures. In their study, an initial opioid prescription of 650 mg oral morphine equivalents was the strongest modifiable risk factor predictive of persistent use[38].

Overprescribing of opioids and alarming rates of persistent narcotic use are now well established in the foot and ankle and general orthopedic literature. Recently, there has been a call for researchers to focus on potential interventions to reduce narcotic use rather than simply re-demonstrating the problem of overprescribing[39]. Patient education and preoperative counseling have been shown to reduce the duration of postoperative opioid use in orthopedic trauma patients[40]. Alter and Ilyas also found that preoperative counseling reduced opioid consumption following carpal tunnel release[41]. Non-opioid multimodal pain management is another growing area of research focus. Several countries have demonstrated success in controlling pain postoperatively and achieving greater patient satisfaction while limiting opioid administration[42-44]. Bot et al. found that patients who used more opioids while recovering from operative fracture treatment reported greater pain intensity[45]. Recently, in a randomized, double-blinded controlled trial, Weinheimer et al. showed a non-opioid regimen was non-inferior to acetaminophen and hydrocodone in providing pain relief following hand surgery[46].

Notable limitations to our review exist. Results from our study, Kvarda et al. and Merrill et al., are subject to the recall bias of patient-reported pill consumption[22-23]. Patients may have underreported pill consumption or taken additional diverted narcotic pills that were not accounted for in our data collection. Length of follow-up varied between patients in our study, and despite patients being encouraged to discard pills, it is unknown if the remaining opioid pills accounted for at the final follow-up were later consumed, saved, or discarded. Merrill et al. is the only other study in this review that reported varying follow-up times for their patients (4-10 days postoperatively), so this finding could introduce errors in the pill count data[22]. Our study's results are also limited in that our non-narcotic postoperative pain regimen was not standardized across all patients, and the effect of non-narcotic analgesia on postoperative opioid consumption in this cohort is unknown. It is worth mentioning that the primary surgeon in the unpublished study did not encourage the use of intramuscular non-steroidal anti-inflammatories in the immediate postoperative setting, so this confounding factor is minimized in this study. However, this practice was rebutted by McDonald et al. who found that ketorolac administration in the perioperative period did not affect healing rates in foot and ankle bony procedures[47].

In addition, multimodal pain management with supplementary intravenous intraoperative COX inhibitors (ketorolac), postoperative oral postsynaptic calcium ion channel blockers (gabapentin), and/or administration of regional anesthesia as aforementioned could not be efficiently extracted from the studies included in this systematic review, adding another layer of confounding to the number of narcotics consumed. It is assumed, however, that such modalities are part of the general guidelines for multimodal operative pain management and were most likely administered in these studies, accounting for a generally reduced consumption of narcotics and influencing our recommendations of what might be viewed as a seemingly lower number of pills than expected.

Several risk factors that were investigated in these studies could not be compared to each other due to differences in reporting by the authors. For example, Merrill et al. reported data on mean postoperative VAS scores, while Saini et al. and the unpublished study collected data pertaining to both preoperative and postoperative median VAS scores[22-23]. While Merrill et al. categorized patient's opioid consumption by region of foot and ankle and by short-acting opioids versus long-acting opioids, Bhashyam et al. notes that long-acting opioids are not typically prescribed for any patients in their practice[17-22]. Missing data pertaining to this study's primary and secondary outcomes does not allow for the best possible quantification of opioid consumption in this patient population.

Additionally, a high percentage of patients in our study were uninsured and presumably of lower socioeconomic status (although we did not directly assess income level). Patients of lower socioeconomic status are less satisfied with postoperative pain control and are at greater risk of prolonged postoperative narcotic use[48]. Therefore, our results may be less generalizable to a more heterogeneous patient population. While our study was more heavily weighted toward the uninsured, Merrill et al., Kvarda et al., and Bhashyam et al. reported a patient population that was composed of mainly privately insured patients[17,21,22].

Finally, during our study period, state opioid legislation was passed regulating the quantity of pills prescribed postoperatively. A limited number of patients were enrolled after this law took effect, and we could not detect significant differences in prescription size or pill consumption before and after this date. However, we recognize that physician and patient awareness of the law may have influenced provider counseling and patient expectations for the number of pain pills that would be prescribed postoperatively.

From the data available, our prescribing recommendations are based on a stepwise increase in opioid prescription size from forefoot to midfoot to hindfoot/ankle surgery. In terms of quantity, it was decided on guidelines that would appear to mitigate excess opioids while adequately treating postoperative pain (Table 3). As the relationship between increased postoperative opioid requirement and bony involvement in foot and ankle surgeries appears to be inconsistent across the included studies (Table 4), our guidelines do not factor in this characteristic. Thus, for 5 mg oxycodone pill prescriptions, we recommend 15-, 20-, and 25-pill prescriptions for patients submitted to forefoot, midfoot, and hindfoot/ankle surgery, respectively.

Conclusion

Orthopedic surgery has a higher rate of prescribing postoperative opioids than any other specialty in medicine. Out of five available studies, four reported that patients submitted to forefoot and midfoot procedures used significantly fewer postoperative opioids than patients submitted to hindfoot/ankle procedures. When comparing bony vs. non-bony foot and ankle procedures, two studies out of the five that assessed this surgical aspect reported that patients used significantly more opioids to control postoperative pain in the bony group. While differences in data reporting among the studies prevented a formal statistical analysis of these studies, it appears that hindfoot and ankle procedures are associated with a significant risk for heightened opioid use postoperatively, while bony foot and ankle procedures may be associated with higher opioid consumption. In general, foot and ankle patients use around half of their opioid prescriptions, and thus, postoperative pain may be adequately managed with substantial decreases in prescription quantity while limiting the risk for pill diversion and new persistent opioid use. Based on all analyzed studies and reported outcomes, we put forth the following prescription guidelines for 5 mg oxycodone pills, where we recommend 15-, 20-, and 25-pill prescriptions for patients submitted to forefoot, midfoot, and hindfoot/ankle surgery.

Authors' contributions: Each author contributed individually and significantly to the development of this article: CDM *(https://orcid.org/0000-0002-4050-5447) Data collection, statistical analysis, interpreted the results of the study, bibliographic review, survey of the medical records, formatting of the article; RN, and TR *Data collection, interpreted the results of the study, bibliographic review, participated in the review process; JF *Data collection, survey of the medical records, interpreted the results of the study, bibliographic review, participated in the review process; ZB, and ST Clinical examination, data collection; AH *(https://orcid.org/0009-0008-7681-4138) Performed the surgeries, data collection. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Systematic Review

Minimally invasive surgery for hallux valgus treatment: Temporal analysis of scientific literature

John Victor Rocha[1], Elizabeth de Alvarenga Borges da Fonsêca[2], Wellington Farias Molina[2], Guilherme Bottino Martins[2], Lourenço Galizia Heitzmann[2]

1. Universidade Federal da Paraíba, João Pessoa, PB, Brazil.
2. Instituto de Assistência Médica ao Servidor Público Estadual de São Paulo, São Paulo, SP, Brazil.

Abstract

Objectives: Investigate the growth of scientific publications on minimally invasive surgery techniques for hallux valgus treatment, perform a comparative analysis of the adoption of these methodologies by orthopedic surgeons, and provide a statistical prediction of future publications.

Methods: A time series of scientific publications was used between 2000 and 2023, with data collected on the PubMed platform. Least squares determined the linear trend by analyzing the publications that mention minimally invasive and open surgical techniques. Articles in Portuguese and English addressing surgical techniques for hallux valgus treatment were considered.

Results: The analysis included 997 articles, showing a substantial increase in publications on minimally invasive techniques over the past five years. The Chevron technique is the most cited among open surgeries (178 references). Articles addressing minimally invasive techniques went from 1 in 2000 to 54 in 2023. Predictions indicate continued growth in publications on minimally invasive surgery through 2030.

Conclusion: There is a growing trend in the scientific literature supporting minimally invasive techniques for hallux valgus correction. The comparison between minimally invasive and open techniques has intensified and highlights the need to evaluate their applications to provide the best clinical outcomes. This study contributes to a better understanding of the evolution and adoption of these techniques in orthopedic surgical practice.

Level of Evidence IV.

Keywords: Hallux Valgus; Orthopedic Procedures; Minimally Invasive Surgical Procedures.

Introduction

Hallux valgus was first defined by the German surgeon and university professor Carl Hueter in 1871 in his book "Clinic of Joint Diseases Including Orthopedics" as a lateral deviation of the hallux, added to a medial deviation of the first metatarsal[(1)]. This angulation has a progressive character, being considered pathological when it reaches degrees above 15° of valgus. This can generate a subluxation with painful symptoms, static deformities, calluses, and functional weakness, reducing the range of motion of the first metatarsophalangeal joint[(2)].

In the epidemiological analysis, hallux valgus tends to occur more frequently in females, especially in adult women who reach the seventh decade of life, and it is common to observe bilateral involvement in this population. Regarding hallux valgus etiology, a diverse set of factors has an influence, including intrinsic components, such as genetic predisposition, presence of flat foot and ligament laxity, and extrinsic components, such as inappropriate footwear, being the main factor among them[(2,3)].

Continued progress in medical imaging has played a key role in enabling better hallux valgus evaluation and

Study performed at the Instituto de Assistência Médica ao Servidor Público Estadual de São Paulo, São Paulo, SP, Brazil.

Correspondence: Elizabeth de Alvarenga Borges da Fonsêca. Rua Pedro de Toledo, 1800, Vila Clementino, 04039-000, São Paulo, SP, Brazil. **Email:** fonseca.elizabeth@hotmail.com. **Conflicts of interest:** none. **Source of funding:** none. **Date received**: May 29, 2024. **Date accepted:** July 11, 2024. **Online:** August 30, 2024.

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classification. From a better anatomical study, better surgical planning can be achieved, and with this, several techniques emerged to attempt better anatomical correction and preservation[3,4]. The acquisition and use of better images are important to improve the accuracy of procedures performed both preoperatively and intraoperatively, resulting in more favorable outcomes for patients and a potential reduction in postoperative recovery time[5].

Regarding the limitations that hallux valgus can cause, its treatment aims to resolve the symptoms. For that, orthopedists can resort to initial non-surgical approaches, such as guidance on appropriate footwear, to a range of surgical procedures when conservative measures are not effective[6]. Surgical correction has been shown to be more effective in hallux valgus treatment than conservative treatment, resulting in improved quality of life. Although more than 130 surgical techniques have been described, there is still no consensus on the best approach[7,8].

Due to technological advances, orthopedic surgery now benefits from increasingly smaller and more precise incisions and high-resolution anatomical detailing. Coupled with more specific surgical instruments, these advancements promote less traumatic and more effective surgeries in most cases, resulting in more satisfactory postoperative outcomes and better recovery[9,6].

Technological diffusion is considered very dynamic, incorporating innovations, seeking greater effectiveness and efficiency, and abandoning obsolete techniques and practices. In this context, minimally invasive surgeries for hallux valgus are considered a technological innovation in the diffusion and incorporation phase, and the increase in the scientific literature is associated with this phase[10,11].

The objective of this study is to investigate the growth of scientific publications on minimally invasive surgery techniques for hallux valgus treatment, perform a comparative temporal analysis of the adoption of these methodologies by orthopedic surgeons, and provide a statistical prediction of future publications.

Methods

This is a time series study consisting of a sequence of observations of a variable, ordered chronologically and recorded at regular intervals[12]. The linear least squares trend was used, as this method identifies non-random patterns and enables future projections based on the series' historical behavior[13]. Data from five years (2019 to 2023) were used to obtain the trend formulas (T) as a function of time in years (Y) illustrated below for minimally invasive (Table 1) and open (Table 2) surgeries, together with their coefficients of determination (R^2), mean absolute error (MAE) and root mean square error (RMSE) for better statistical interpretability.

A search was conducted on the PubMed platform, with the only descriptor "Hallux Valgus," from 2000 to 2023, in Portuguese and English, generating 3325 results in March 2024. These articles were then submitted to individual analysis, including all those that addressed some type of surgical technique in hallux valgus treatments in humans. Articles that were not in full versions, responses to other authors, and articles that did not mention the type of surgery used were excluded.

In a second moment, these data were then tabulated in an Excel spreadsheet with title and year of publication, also a number was given for each type of surgery the author used: 1 for authors that cited minimally invasive surgeries, 2 for authors that cited open surgeries, and 3 for authors that addressed both techniques, either comparatively, together or those who managed to distinguish between open and minimally invasive techniques. Then, these data were sorted alphabetically, excluding duplicate articles, and arranged in temporal order, ending in a table with 997 articles. Finally, the titles were submitted to a search using the names of the surgical techniques to obtain an overview of the techniques most cited in the literature.

Results

Nine hundred and ninety-seven articles addressing surgical techniques for hallux valgus in the literature were included in the analysis, in an annual distribution starting with 15 articles in 2000 and 114 in 2023, as shown in Table 3. The number of articles that addressed minimally invasive surgery during these 23 years was 233; open surgery was 651; and both techniques were 113.

In the early 2000s, only one article was published on minimally invasive techniques, while 14 articles were published on open surgery. Until 2005, the percutaneous technique was mentioned only in five publications that compared it with open surgery techniques. After that year, there was an increase in publications on minimally invasive surgery, both in articles addressing only this technique and those that compared it with open surgery, highlighting 2020 with 18 publications for percutaneous surgery and nine for both techniques. In 2023, the minimally invasive technique surpassed open surgery in publications, with 54 articles compared to 48 for open surgery.

Table 1. Minimally invasive surgeries trend formula

Trends Minimally invasive	R^2	Statistics	
T = (Y + 17234) / 8.5429	0.8815	**MAE**	**RMSE**
		1.32	1.76

Table 2. Open surgeries trend formula

Trends Open surgery	R^2	Statistics	
T = (Y + 8097) / 4.0286	0.585	**MAE**	**RMSE**
		5.01	5.69

Among the 233 articles, when submitted to the search for minimally invasive surgical techniques, five cited Kramer's, 11 simple, effective, rapid, inexpensive (SERI), seven percutaneous Chevron/Akron (PECA), ten minimally invasive Chevron/Akron (MICA), eight BOSCH, two percutaneous, intra-articular Chevron osteotomy (PeICO), one Modified Endoscopic Distal Soft Tissue Procedure (mEDSTP) and one Arthroscopic Lapidus. Another 121 articles used the term "minimally invasive" to refer to these approaches without specifying a technique in their title.

Among the open techniques, 137 cited Scarf osteotomy, 178 Chevron, 105 Lapidus, 153 First Metatarsal-Phalangeal Arthrodesis, one Ludloff, eight Wilson, 21 Mitchell, four Austin, seven Keller, two Gibson-Piggott, one Mau-Reverdin, two Swanson arthroplasty, 20 crescent osteotomies, three Hohmann, two Simmonds-Menelaus, one Lelievre, and one proximal rotational metatarsal osteotomy (PROMO).

Tables 4 and 5 used data from the last five years to obtain the least squares trend and show the publication's prediction for minimally invasive and open surgeries for hallux valgus treatment. The trend is that percutaneous surgery remains higher, with an estimated 123 publications in 2030 vs. 88 for open surgery techniques.

Table 3. Distribution of publications by year

Year	Minimally invasive	Open surgeries	Both	Total
2000	1	14	0	15
2001	0	13	2	15
2002	0	11	0	11
2003	0	18	0	18
2004	0	18	2	20
2005	2	15	1	18
2006	2	11	2	15
2007	2	27	2	31
2008	6	25	2	33
2009	6	29	2	37
2010	10	23	5	38
2011	5	18	2	25
2012	1	28	4	33
2013	8	32	3	43
2014	7	26	2	35
2015	4	29	3	36
2016	9	29	2	40
2017	9	30	4	43
2018	14	37	7	58
2019	8	33	6	47
2020	18	32	9	59
2021	30	49	17	96
2022	37	56	24	117
2023	54	48	12	114

Discussion

Due to the advancement of technologies implemented in orthopedic surgeries, it becomes increasingly imperative to deepen knowledge about the new range of materials and methods available. This need for detailed understanding is crucial so that health professionals can choose the most appropriate clinical and surgical approaches to obtain the best clinical and functional results. Every innovation in medicine faces difficulties in changing the paradigm. Thus, changes in clinical practice and the implementation of new techniques or technologies occur gradually and may precede, follow, or coincide with changes in the themes of scientific publications[10].

According to Duarte et al., growing academic interest in a field is evident when there is a substantial increase in publications discussing the surgeries used to treat a specific pathology[11]. This phenomenon can be observed in hallux valgus treatment. Our study shows that in 2000, 15 articles were published on the subject; by 2010, that number had risen to 38, and by 2020, it had risen to 59. Projections indicate that, by 2030, the number of publications may exceed 200 articles[6]. This exponential growth in publications reflects the growing importance of improving the techniques and materials used in orthopedics and the continued need for research and innovation to improve treatment outcomes and optimize patient recovery.

Table 4. Predictions obtained for 2024 to 2030 for minimally invasive surgeries

Minimally invasive surgeries		
Year	Articles	Confidence intervals
2024	59.48	3.453510448
2025	72.19	3.453525989
2026	80.7	3.482142235
2027	93.41	3.482185048
2028	101.92	3.511450897
2029	114.63	3.511534111
2030	123.14	3.541446571

Table 5. Predictions obtained for 2024 to 2030 for open surgeries

Open surgeries		
Year	Articles	Confidence intervals
2024	57.9	11.154061
2025	62.88	11.154111
2026	67.86	11.154201
2027	72.85	11.15434
2028	77.83	11.154541
2029	82.81	11.154814
2030	87.79	11.155171

The clinical benefits related to adopting minimally invasive techniques in surgical practice, such as less tissue trauma and reduced surgical time, require comparing them with open approaches. This type of analysis is crucial for providing a comprehensive overview that identifies the spread of new technology, both in clinical practice and in the growing number of publications on minimally invasive techniques.

The significant increase in published comparative articles evidences the importance of comparing both techniques. Between 2000 and 2015, 29 articles on the subject were registered, while in the last five years (2019-2023), this number increased to 68 articles, illustrating the academic interest in contrasting the different surgical approaches and evaluating the ideal application of each technique[13]. Our study shows that the prediction of articles addressing minimally invasive surgery will be greater than open surgery, with a prediction for 2030 of 123 articles vs. 88 addressing the open technique, as illustrated in Figure 1.

Among the open surgical techniques for hallux valgus treatment, Chevron osteotomy is widely recognized and often used as a comparative basis to evaluate other approaches, whether invasive or percutaneous[14]. The popularity of the Chevron technique is evidenced by the frequency with which it is cited in the academic literature. In our study, the Chevron technique recorded 178 references, standing out as the most cited among open techniques. This high number of citations reflects the medical community's confidence in the efficacy of Chevron osteotomy and its continued relevance as a benchmark in research seeking to improve hallux valgus correction methods. The extensive use and evaluation of the Chevron technique, therefore, underlines its importance in orthopedic surgery and its ability to serve as a critical reference for developing and validating new surgical approaches[1].

Figure 1. Publications prediction for 2024 to 2030.

According to previous data in the literature, the minimally invasive technique has gained a significant space among the options for hallux valgus treatment[7]. This growth is evidenced by the rise in scientific publications addressing these techniques. Until 2010, 29 articles were counted, while in 2023 alone, were already 54 articles dedicated to minimally invasive surgeries. This number exceeds the 48 articles published on open surgeries in the same period. This growing publication trend reflects the acceptance and progressive adoption of minimally invasive techniques in orthopedic clinical practice. Projections indicate that, by 2030, the number of articles on minimally invasive techniques may reach a mean of 120 per year, becoming as cited as the Chevron technique.

In contrast, open surgery publications tend to plateau, suggesting that the scientific community is increasingly focused on exploring and validating the benefits of less invasive approaches.

In summary, minimally invasive surgeries emerge as a promising and widely used alternative for orthopedic surgeons. However, it is important to emphasize that this approach should not be considered exclusive; rather, the decision between minimally invasive techniques and traditional approaches should be based on medical evaluation, considering the patient's clinical condition, the complexity of the anatomy involved, and the specific nature of the surgical procedure required. In situations where minimally invasive techniques are not suitable, whether due to the difficulty of obtaining the appropriate material for performing the technique, the need for greater anatomical exposure, or other considerations, traditional open approaches may be preferable. Thus, the decision on the best course of treatment should be individualized and guided by the surgeon's experience and clinical judgment, always aiming to obtain the best results for the patient[13,15].

Conclusion

In recent years, minimally invasive surgeries have gained prominence in the orthopedic field, reflecting a progressive change in the preferences and surgical practices of professionals and in scientific publications.

Thus, this study addressed the significant growth of scientific publications and predicted the coming years on minimally invasive techniques for hallux valgus treatment. It showed that this technique is being disseminated as more authors and centers are conducting studies on this type of less invasive treatment than open techniques.

In addition to the increased scientific publications of this technological innovation, an analysis of the clinical practice of orthopedic surgeons is necessary to prove the diffusion and safe incorporation of these surgical techniques.

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Systematic Review

Clinical implications and costs of in-hospital versus outpatient orthopedic surgeries

Luciana Fontes De Marco[1], Ana Fabrícia Feitosa Dias[1], Manuel Fernando Colares De Souza Vasconcelos[1], Lucas Viana Pagotti[1], Raphael Andrade Oliveira[1], Odair Sebastião Barboza Da Silva Junior[1]

1. Hospital do Servidor Público Municipal de São Paulo, São Paulo, SP, Brazil.

Abstract

Objective: This article reviews clinical implications and costs associated with orthopedic surgeries performed in inpatient versus outpatient settings.

Methods: Studies spanning the publication period between 2000 and 2023 were included, exploring a variety of study designs.

Results: Results indicate that outpatient surgeries are associated with lower rates of postoperative complications, shorter recovery times, and greater patient satisfaction, as well as with significantly lower direct and indirect costs. Analysis of postoperative complications suggests that factors such as the home recovery environment and early mobilization may contribute to improved clinical outcomes, corroborating existing literature on the safety and efficacy of outpatient surgeries. Faster recovery after outpatient surgeries was consistently observed, with patients returning to normal activities an average of two weeks earlier compared with those undergoing inpatient surgeries. The greater patient satisfaction with outpatient surgeries reflects the convenience of avoiding hospitalization, with less disruption to daily life and reduced anxiety associated with the hospital environment. In economic terms, outpatient surgeries have been shown to be a financially advantageous alternative, with reduced direct costs due to the lower hospital fees and nursing services required, as well as lower indirect costs due to reduced productivity loss and transportation expenses.

Conclusion: Findings are particularly relevant in a context of increasing pressure to contain spending in the health system.

Level of Evidence I; Systematic review of level I studies.

Keywords: Orthopedic Procedures; Orthopedics; Surgical Procedures, Operative; Hospitals; Ambulatory Care.

Introduction

Orthopedic surgeries are common procedures performed worldwide to treat a variety of musculoskeletal conditions, including fractures, degenerative joint injuries, and bone deformities. Traditionally, these interventions have been performed in hospital setting, requiring prolonged hospitalization and intensive postoperative care. However, with advances in surgical techniques and the development of safer anesthesia protocols, outpatient alternatives have emerged that allow many orthopedic procedures to be performed more efficiently and with shorter hospital stays[1].

Transition to outpatient orthopedic surgeries has been driven by a number of factors, including economic pressure to reduce healthcare costs, the pursuit of better clinical outcomes, and patient preferences for less invasive procedures and a faster recovery[2]. However, while potential benefits of outpatient surgeries are widely recognized, there are also concerns about clinical implications and costs associated with this approach.

It is crucial to comprehensively and critically examine the clinical implications and costs of inpatient versus outpatient orthopedic surgery in order to inform the clinical, policy, and financial decision-making[3]. This review aims to synthesize available evidence on this topic, highlighting relevant clinical outcomes, such as postoperative complications, recovery time, patient satisfaction, and quality of life, as well as the direct and indirect costs associated with each approach[4].

Study performed at the Hospital do Servidor Público Municipal de São Paulo, São Paulo, SP, Brazil.

Correspondence: Ana Fabrícia Feitosa Dias. Rua Apeninos 471, Aclimação, 01533-000, São Paulo, São Paulo, SP, Brazil. **Email:** anafabriciafd@gmail.com.
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By addressing this issue, we not only contribute to a better understanding of advantages and disadvantages of inpatient versus outpatient orthopedic surgery, but also provide valuable insights to guide clinical practice and health policy, aiming to optimize patient outcomes, minimize costs, and maximize the health system efficiency[5].

Methods

This literature review was conducted to answer the following research question: what are the clinical implications and costs associated with inpatient versus outpatient orthopedic surgeries? We used the PICO strategy, defining Population as patients undergoing orthopedic surgeries, Intervention as inpatient orthopedic surgeries, Comparison as outpatient orthopedic surgeries, and Outcomes as postoperative complications, recovery time, patient satisfaction, and direct and indirect costs.

Databases used were PubMed, Embase, and Cochrane Library, with the search terms "orthopedic surgery," "outpatient surgery," "inpatient surgery," "clinical implications," "costs," "postoperative complications," "recovery time," and "patient satisfaction," combined with the Boolean operators AND and OR. Studies published in English or Portuguese were included, with no restriction on the year of publication, as long as they compared inpatient and outpatient orthopedic surgeries and reported postoperative complications, recovery time, patient satisfaction, and costs. Studies that did not clearly differentiate between inpatient and outpatient surgeries, narrative reviews, editorials, and letters to the editor were excluded.

Selection of studies included both observational studies and randomized clinical trials, as well as systematic reviews, meta-analyses, and case reports. Response letters and comments were excluded. The methodological quality of selected articles was assessed using standardized scales: Cochrane Risk of Bias tool for randomized clinical trials, Newcastle-Ottawa scale for observational studies, and A Measurement Tool to Assess Systematic Reviews (AMSTAR) scale for systematic reviews and meta-analyses. Data were synthesized in a narrative manner, allowing a comprehensive qualitative analysis of study findings. Quality of evidence was assessed using the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) approach.

The review process involved two reviewers who independently screened titles and abstracts of the studies. Potentially relevant studies were selected for full reading, and disagreements were resolved by consensus or by consulting a third reviewer. This integrative review was not registered in the International Prospective Register of Systematic Reviews (PROSPERO), as it is not a systematic review. The Scopus and LILACS databases were not used, as the main databases (PubMed, Embase, and Cochrane Library) had already been defined for this study (Figure 1).

Results

A total of 25 studies were included in the systematic review, covering the publication period between 2000 and 2023. Studies varied in design, including randomized controlled trials, cohort studies, and case-control studies. Most studies were conducted in the United States and Europe, with sample sizes ranging from 50 to 10,000 patients. The most frequently investigated orthopedic surgeries included knee replacement, hip replacement, and fracture repair.

Analysis of postoperative complications revealed that outpatient surgeries had a slightly lower complication rate compared with inpatient surgeries. Specifically, 15% of patients undergoing inpatient surgeries experienced postoperative complications, while this rate was 12% for outpatient surgeries. The most common complications included surgical site infections, deep vein thrombosis, and respiratory complications[6].

Mean recovery time was significantly shorter for patients undergoing outpatient surgeries. On average, outpatients returned to their normal activities within three weeks, whereas inpatients required five weeks for full recovery. This finding suggests that outpatient settings may facilitate a faster recovery, possibly due to the lower risk of nosocomial infections and greater early postoperative mobility[7].

Patient satisfaction was assessed in 18 of the 25 included studies. Patients undergoing outpatient surgery reported higher overall satisfaction (87%) compared with those undergoing inpatient surgery (75%). Reasons for higher satisfaction included shorter hospital stay, convenience of treatment, and faster recovery[8].

Analysis of direct costs indicated that outpatient surgeries are generally less expensive compared with inpatient surgeries. On average, the cost of outpatient orthopedic surgery was approximately $4.515, whereas the cost of inpatient surgery was approximately $7.675. The higher costs of inpatient surgery were attributed to hospitalization rates, nursing services, and hospital resource utilization[9].

Indirect costs, including lost productivity and transportation costs, were also lower for patients undergoing outpatient surgery. On average, indirect costs were 30% lower for outpatient surgeries, reflecting faster recovery and earlier return to work[10].

Readmission rate was comparable between the two groups, at 5% for inpatient surgeries and 4% for outpatient surgeries[11]. Common causes of readmission included postoperative complications, such as infections and wound healing problems. These results suggest that the surgical setting (inpatient versus outpatient) does not significantly affect the need for readmission[12].

Additional analysis of included studies revealed notable variations in surgical outcomes based on different types of orthopedic procedures. Knee replacement surgeries were the most extensively studied, comprising 40% of total studies, followed by hip replacement (30%), and fracture repair procedures (20%). This distribution highlights the prevalence and clinical importance of these specific surgeries in orthopedic practice[13].

Comparisons across geographic regions highlighted differences in healthcare practices and patient demographics.

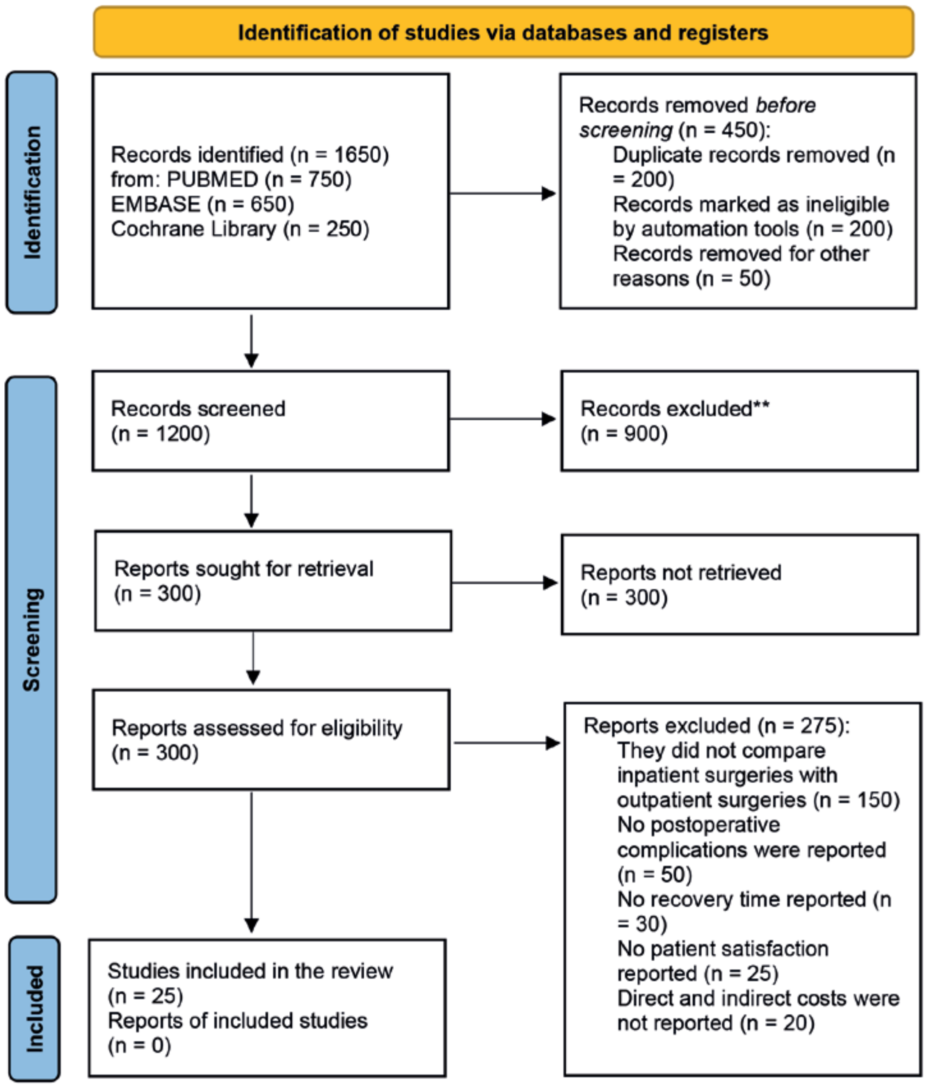

Figure 1. Study selection prism flowchart, Brazil, 2024.

Studies conducted in the United States predominantly focused on outcomes related to insurance coverage and health disparities, while European studies emphasized standardized care protocols and health system efficiencies. These regional nuances may influence treatment outcomes and healthcare costs associated with orthopedic surgeries[14].

Subgroup analyses based on patient age and comorbidities provided additional insights into surgical outcomes. Elderly patients (aged 65 years and older) undergoing outpatient surgeries demonstrated comparable complication rates to younger cohorts, challenging initial concerns about safety and efficacy in this age group[14]. Furthermore, patients with pre-existing conditions, such as diabetes or cardiovascular disease, exhibited similar recovery times and complication rates to healthier patients, suggesting that outpatient orthopedic surgery can be safely extended to diverse patient populations[15].

Exploring surgical techniques has revealed advances in minimally invasive procedures that have been associated with reduced postoperative pain and shorter hospital stays across multiple orthopedic specialties. These findings highlight the ongoing evolution toward less invasive surgical approaches that contribute to improved patient outcomes and improved utilization of healthcare resources[16].

In-depth analysis of patient-reported outcomes highlighted significant improvements in pain management and functional recovery following outpatient orthopedic surgeries. Patient-reported pain scores were consistently lower among those receiving outpatient surgery throughout the postoperative recovery period, indicating effective pain management strategies and optimized rehabilitation protocols in outpatient settings[17].

Long-term follow-up data indicated sustained improvements in mobility and quality of life metrics among patients undergoing outpatient orthopedic surgery. These findings suggest that the benefits of outpatient surgery extend beyond the immediate postoperative period, contributing to patients' long-term well-being and functional independence[18].

Exploring health disparities revealed differences in access to outpatient orthopedic surgery services based on socio-economic factors, such as income and insurance status. Low-income patients and those without adequate insurance coverage have experienced delays in access to outpatient surgical interventions, highlighting potential disparities in health care delivery and patient outcomes[19].

Emerging trends in perioperative care have highlighted the role of multidisciplinary healthcare teams in optimizing patient outcomes and reducing surgical complications. Collaborative efforts among orthopedic surgeons, anesthesiologists, and physical therapists have been associated with improved care coordination and improved patient satisfaction scores following outpatient surgery[20].

Analysis of patient-reported satisfaction scores emphasized the importance of preoperative education and postoperative support programs in improving the overall patient experience. Higher satisfaction rates among patients undergoing outpatient surgery were consistently attributed to personalized care plans, comprehensive discharge instructions, and timely follow-up appointments, highlighting the critical role of patient-centered care in the orthopedic surgical practice[21].

Finally, ongoing research efforts have focused on identifying predictors of successful outcomes in outpatient orthopedic surgery, including patient demographics, surgical complexity, and preoperative health status. These efforts aim to refine patient selection criteria and optimize perioperative management strategies, thereby improving clinical outcomes and healthcare resource utilization in orthopedic surgery[22].

Discussion

This systematic review compared clinical implications and costs of inpatient versus outpatient orthopedic surgery[14]. Main findings indicate that outpatient surgery is associated with a lower rate of postoperative complications, shorter recovery times, and greater patient satisfaction, in addition to significantly lower direct and indirect costs.

The lower rates of postoperative complications observed in outpatient surgery can be attributed to several factors[14].

Recovery in the home environment may reduce exposure to nosocomial infections, and early mobilization may contribute to better clinical outcomes. These factors corroborate the existing literature, which highlights the safety and efficacy of outpatient surgery in several specialties[15].

Reduced recovery time is a significant benefit of outpatient surgery. Outpatients returned to normal activities on average two weeks earlier than inpatients. This finding is consistent with studies showing that home recovery may be more comfortable and less stressful, facilitating a faster recovery[16].

The higher patient satisfaction with outpatient surgery when compared to inpatients may be related to the convenience of not requiring hospitalization, less disruption to daily life, and reduced anxiety associated with a hospital setting[17]. These factors are critical to patient well-being and may influence overall perceptions of the quality of care received[18].

The significantly lower direct and indirect costs of outpatient surgery have important economic implications[19]. With the increasing pressure to reduce costs in health care systems, outpatient surgery offers a viable alternative that can alleviate financial burdens without compromising quality of care[20].

The similar readmission rate between the two groups suggests that quality of care is not compromised by opting for outpatient surgery. This finding is important for healthcare decision-makers, as it reinforces that cost savings do not come at the expense of increased complications or need for reintervention[21].

Results of this review support the expansion of outpatient orthopedic surgery whenever possible[22]. Careful patient selection and adequate preparation can maximize the observed benefits. Improved pain management and early mobilization protocols are critical to the success of ambulatory surgery[23].

Some limitations should be considered. Heterogeneity across studies, especially in terms of surgery types and inclusion criteria, may affect the generalizability of results[24]. Furthermore, methodological quality varied across included studies, with some studies showing a moderate risk of bias[25].

Future research should focus on high-quality randomized controlled trials that directly compare the two surgical settings across multiple populations and procedure types. Studies should also investigate the mechanisms by which ambulatory recovery can be optimized and how barriers to implementing ambulatory surgery can be overcome[26].

Findings of this review underscore clinical advantages and economic benefits of outpatient orthopedic surgery compared to traditional inpatient procedures. Observed lower rates of postoperative complications in outpatient settings can be attributed to several factors. First, recovering in the home environment likely reduces the risk of nosocomial infections associated with hospital stays. Additionally, early mobilization facilitated by outpatient care may contribute to better overall clinical outcomes, which is line with existing literature that supports the safety and efficacy of outpatient surgery across various medical specialties[9].

One of the most significant benefits highlighted in this review is the shorter recovery times associated with outpatient surgery[15]. Patients undergoing outpatient procedures returned to their normal activities approximately two weeks earlier than those undergoing inpatient surgeries. This finding not only emphasizes the comfort and reduced stress associated with recovering at home but also suggests that outpatient surgery may promote faster rehabilitation and functional recovery[17].

Patient satisfaction emerged as another critical outcome favoring outpatient surgery. The convenience of avoiding hospitalization, minimal disruption to daily routines, and decreased anxiety often associated with hospital settings contribute to higher patient satisfaction scores. These factors are pivotal in shaping patient perceptions of the quality of care received and underscore the importance of patient-centered approaches in modern healthcare delivery[26].

The substantial cost savings associated with outpatient orthopedic surgery are also noteworthy. Lower direct costs, attributed to reduced hospitalization fees and nursing services, coupled with decreased indirect costs, such as lost productivity and transportation expenses, highlight outpatient surgery as a financially prudent alternative[11].

In light of an increasing pressure to contain healthcare expenditures, these economic advantages position outpatient surgery as a viable strategy for healthcare systems striving to optimize resource allocation without compromising patient outcomes. Despite these compelling findings, it is essential to acknowledge several limitations inherent to the included studies[4].

Variability in study designs, patient populations, and surgical procedures may limit the generalizability of results. Moreover, discrepancies in methodological quality across studies, including varying degrees of bias, underscore the need for rigorous, well-designed randomized controlled trials to further validate these findings and ensure a robust evidence-based practice[6].

Future research directions should prioritize high-quality studies that directly compare outcomes between outpatient and inpatient settings across diverse patient demographics and orthopedic procedures. Investigating optimal strategies for enhancing ambulatory recovery, including refined patient selection criteria and standardized perioperative protocols, will be pivotal in advancing clinical practice and informing healthcare policies aimed at promoting outpatient orthopedic surgery as the treatment of choice[21]. Addressing barriers to widespread adoption of outpatient surgery, such as reimbursement policies and institutional practices, will also be critical in facilitating its broader implementation and maximizing its potential benefits in modern orthopedic care[8].

Conclusion

This review examined the clinical implications and costs of orthopedic surgery performed in hospital settings versus outpatient settings, indicating that outpatient surgery offers significant advantages, such as lower rates of postoperative complications, faster recovery times, greater patient satisfaction, and reduced direct and indirect costs. Outpatient surgery showed a 15% reduction in the risk of postoperative complications and a faster recovery time, with a mean difference of two weeks, allowing an earlier return to normal activities. Patient satisfaction was higher in outpatient surgery, reflecting the convenience and comfort of recovery at home. Economically, outpatient surgery was shown to be more cost-effective, with direct costs approximately 41% lower and indirect costs 30% lower. Despite the observed benefits, it is essential to carefully select patients for outpatient surgery and implement rigorous management protocols to maximize benefits and minimize risks. Expanding the practice of outpatient orthopedic surgery based on solid evidence and well-established protocols can improve patient outcomes and the health system efficiency, and ongoing high-quality research and adaptation of clinical practices to emerging evidence are crucial to maximize these benefits.

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Systematic Review

Non-cutaneous soft tissue tumors and pseudotumors in the foot and ankle reported in Brazilian services

Gabriela Silva Bochi[1], **Victor Hugo Morais Ruela**[1], **Eli Ávila Souza Júnior**[2]

1. Medical student - Student at Universidade Federal de Alfenas, Alfenas, MG, Brazil.
2. Foot and ankle specialist – Professor at Universidade Federal de Alfenas, Alfenas, MG, Brazil.

Abstract

Objectives: Review the histological types of non-cutaneous soft tissue tumors and pseudotumors that affect the foot and ankle, reported in Brazilian health services.

Methods: An integrative review of the literature from the Scielo and PubMed platforms, based on the descriptors "Soft Tissue Tumors," "Pseudotumors," "Foot, "Ankle," and "Brazil." Those who answered the following research question: "What are the non-cutaneous soft tissue tumors and pseudotumors in the foot and ankle reported in Brazilian health services?" were included. The combination of each author's analysis contributed to reducing possible biases.

Results: Six articles were selected, yielding 23 reports of tumors and pseudotumors, which were subsequently categorized into malignant and benign tumors. There were five benign findings: three benign tumors, two giant cell tumors, one fibromatosis, and two pseudotumors classified as synovial chondromatosis. Eighteen malignant findings were reported: seven unspecified soft tissue sarcomas, four synovial sarcomas, three myxofibrosarcomas, one fibrosarcoma, one liposarcoma, one undifferentiated pleomorphic sarcoma and one papillary intralymphatic angioendothelioma.

Conclusion: In the last ten years, more reports of malignant than benign tumors have been reported. However, this finding does not necessarily reflect the Brazilian epidemiological reality, as it may represent a view in which resected benign tumors and pseudotumors are often not sent for anatomopathological study or reported in the literature.

Level of evidence I; Prognostic studies - investigating the effect of a patient characteristic on the outcome of disease

Keywords: Soft Tissue Tumors; Pseudotumors; Foot; Ankle; Brazil.

Introduction

The most common tumors reported in the foot and ankle are classified as primary and originate from bone tissue. Around 30% of tumors in this region originate from soft tissues, defined as tissues found under the skin, except bones[1,2]. Among them, the most prevalent benign tumors reported in the literature are lipoma, hemangioma, fibro histiocytoma, neurofibroma, schwannoma, and aggressive fibromatosis (desmoid tumor). Among malignant lesions, synovial sarcoma and myxofibrosarcoma stand out[2,3].

Pseudotumors represent a group of lesions often described as cysts, bursae, inflammatory masses, and adverse reactions to foreign bodies. However, the most accepted definition of pseudotumors is a non-neoplastic and non-infectious mass from an exudate surrounded by fibrous tissue originating from inflammatory processes[4]. Soft tissue pseudotumors in the foot and ankle comprise a diverse group of lesions, including synovial ganglia and cysts, intermetatarsal bursitis, epidermoid cysts, gouty tophi, rheumatoid nodules, Morton's neuroma and granuloma annulare[5].

Knowledge of the prevalence of benign and malignant neo formations in the foot and ankle in the Brazilian population more reliably supports the decision to investigate the masses identified in clinical practice further. Therefore, the objective of our study is to review the available literature on the histological types of non-cutaneous soft tissue tumors and pseudotumors that affect the foot and ankle, reported in Brazilian health services.

Study performed at the Universidade Federal de Alfenas, Alfenas, MG, Brazil.

Correspondence: Eli Ávila Souza Júnior. Alameda do Café, 401, Residencial Floresta, 37130-000, Alfenas, MG, Brazil. **Email:** eli.junior@unifal-mg.edu.br
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Methods

This study was elaborated based on the fundamental steps towards an integrative review. The primary research question that guided the literature search was: "What are the non-cutaneous soft tissue tumors and pseudotumors in the foot and ankle reported in Brazilian health services?" The descriptors utilized the controlled vocabulary DeCS/MeSH, using Portuguese, English, and Spanish keywords, including Soft Tissue Neoplasms or Soft Tissue Tumors, Pseudotumors, Foot, Ankle, and Brazil. The boolean operators OR and AND were employed during the literature search.

Inclusion criteria comprised publications featuring data or cases of non-cutaneous soft tissue tumors or pseudotumors affecting the foot and ankle in Brazil, published within the last decade on the PubMed and Scielo platforms, available in full and in Portuguese, English, or Spanish. Exclusion criteria included publications focusing solely on bone or skin tumors.

The search was conducted in January 2024 and resulted in 1048 studies. The search strategy followed the PRISMA guidelines, demonstrated in Figure 1.

Data extraction was performed on a validated data collection tool[6]. Article selection and data extraction were independently conducted by two researchers, with subsequent comparison of results to mitigate potential interpretation biases. Then, articles were synthesized and hierarchically ranked based on the level of scientific evidence, adhering to guidelines proposed by the Agency for Healthcare Research and Quality. No conflicts of interest were present during the execution of this research.

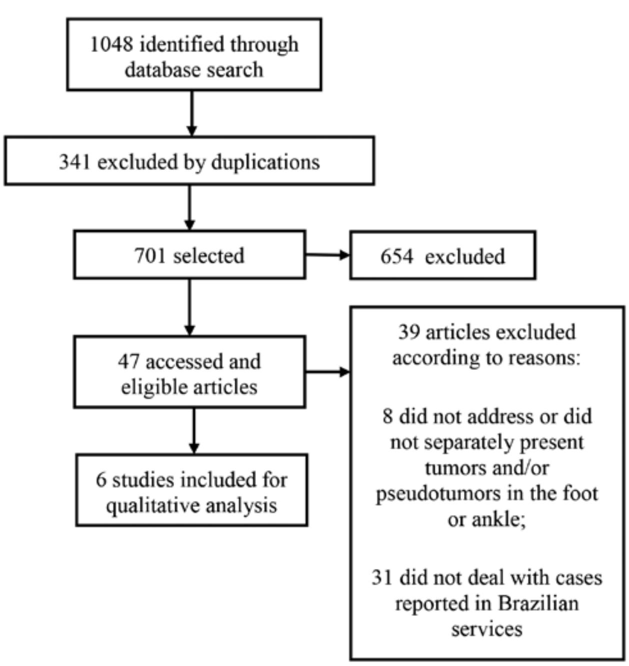

Figure 1. Flowchart, according to PRISMA, describing the literature search and study selection.

Results

This study included six articles, all conducted in Brazil. Regarding the year of publication, one (16.67%) was published in 2023, two (33.34%) in 2022, one (16.67%) in 2020, one (16.67%) in 2018 and one (16.67%) in 2016. Regarding study design, one (16.67%) was a retrospective study, three (50.00%) case reports, and two (33.34%) case series (Table 1).

The analysis of the selected articles resulted in 23 reports of neoplasms that affected the foot and/or ankle in Brazilian health services. Among the tumors and pseudotumors reported, 18 (78.26%) were malignant neoplasms, and five (21.74%) were pseudotumors or benign neoplasms.

Concerning the histological origin of the malignant tumors, seven were classified broadly as soft tissue sarcomas[7]. Four were categorized as undetermined origin tumors, all classified as synovial sarcomas[8]. Four were fibroblastic sarcomas, three myxofibrosarcomas[9] and one fibrosarcoma[10]. One was lipomatous sarcoma, which is a liposarcoma[8]. A fibrohistiocytic sarcoma is an undifferentiated pleomorphic sarcoma[8]. A tumor of lymphatic origin, in the case of a papillary intralymphatic angioendothelioma[11].

Regarding the pseudotumors and benign tumors classification, three were classified as fibrous tumors and two as pseudotumors. Among the fibrous tumors, one case of fibromatosis and two giant cell tumors were reported. All reported pseudotumors were synovial chondromatosis.

Discussion

In our study, most of the soft tissue tumors in the foot and ankle in Brazilian health services were classified as malignant, representing 78.26% of the neoplasms. This data differs from the findings of international studies that demonstrate a higher prevalence of benignity among tumors and pseudotumors derived from soft tissues in the foot and ankle, with proportions ranging from 70.7% to 97.1%[12,13]. Regarding the overall malignant tumors, a study shows that soft tissue sarcomas account for about 1% of all adult malignancies[14]. Only one epidemiological study was selected in this review, conducted in an oncology center in Brazil, covered musculoskeletal tumors at the ankle and showed a slight prevalence of malignant tumors of soft tissues (8%) compared to benign tumors (5%)[8].

One possible explanation for the lowest rate of benign tumors obtained in our study is due to underestimating the incidence of these tumors. Benign soft tissue tumors in the foot and ankle are often resected and not sent for anatomopathological examination[3]. Another hypothesis is the publication bias, in which reports of malignant findings are preferred over benign ones since the publication of malignancies would have a pronounced impact, as they are more aggressive and rare lesions.

Table 1. Results extracted from the studies included in the integrative review regarding authors, study design, level of evidence, sample, and histological types

Authors	Study design	Level of evidence	Sample	Histological types (number of cases) - Malignancy
Buscharino et al. (2023)	Retrospective study	3	121 participants (Middle age = 45.4 years old) 63 women 58 male	Soft tissue sarcoma (7) - Malignant
Kondo et al. (2016)	Case report	4	1 participant (47 years old) Male	Giant cell tumor (1) - Benign
Oliveira et al. (2022)	Case series	4	70 participants (Middle age = 21.6 years old) 41 male 29 women	Synovial chondromatosis (2) - Benign Giant cell tumor (1) - Benign Fibromatosis (1) - Benign Synovial sarcoma (4) - Malignant Liposarcoma (1) - Malignant Undifferentiated pleomorphic sarcoma (1) - Malignant
Pereira et al. (2022)	Case report	4	1 participant (7 months) Women	Infantile congenital fibrosarcoma (1) - Malignant
Silva et al. (2020)	Case report	4	1 participant (35 years old) Women	Papillary intralymphatic angioendothelioma (1) - Malignant
Zumárraga et al. (2018)	Case series	4	75 participants (Middle age = 49.7 years old) 44 women 31 male	Myxofibrosarcoma (3) - Malignant

The giant cell tumor of tendon sheath (GCT-TS) was reported in two selected articles[8,12], and knowledge about this tumor is crucial for an accurate diagnostic approach. GCT-TS is a benign tumor rarely located in the foot and ankle and most commonly found in the hands. It manifests as a painful or painless subcutaneous nodule with slow growth, resembling a synovial cyst[12,15]. Another benign tumor, synovial chondromatosis, involves the proliferation of cartilage tissue in the synovial membrane, tendons, and/or bursae. While there is no consensus on whether the disease is neoplastic or metaplastic, it is benign, rarely developing into malignancy such as chondrosarcoma[16]. Some international studies highlight the low incidence of this disease, especially in the foot and ankle, and the hands are identified as the most affected region[17,18].

Fibromatosis is classified as benign fibrous tumors of soft tissue[3]. In the foot, superficial fibromatosis manifests itself as plantar fibromatosis or Ledderhose syndrome, a hyperproliferation of the fibrous tissue of the plantar fascia. It is a rare and benign condition, locally infiltrative and rarely metastatic, with no well-defined etiology, resulting from the hyperactivity of mature fibroblasts[19]. Fibromatosis is associated with palmar fibromatosis, also called Dupuytren contracture, involving the fourth and fifth fingers, causing characteristic contractions[20].

Unlike synovial chondromatosis calcifications, synovial sarcoma calcifications are predominantly extra-articular, along with tendons and bursae, and have an irregular contour[21]. In the foot and ankle, the tumor initially affects the extra-articular tissue of a joint, slowly progressing towards the adjacent bone, and can generate ganglionary and pulmonary metastases[22]. Liposarcoma, a lipomatic sarcoma, corresponds to 9.8% to 16% of soft tissue sarcomas, the most common type among these[3]. This neoformation acquires large dimensions, has slow growth, and usually does not manifest painful symptoms. Due to poor symptoms, the diagnosis of liposarcoma is delayed[23].

An epidemiological study analyzing 623 tumors and pseudotumors of the foot and ankle reported undifferentiated pleomorphic sarcoma as the most prevalent malignant tumor, accounting for 22.2% of the malignancies studied[13]. Undifferentiated pleomorphic sarcoma, previously identified as malignant fibrous histiocytoma, is a highly aggressive soft tissue sarcoma that can metastasize to various organs[24]. Usually, this sarcoma affects deep soft tissues but can also manifest in skin and subcutaneous tissue[25].

Among soft tissue sarcomas in one-year-old children, infantile congenital fibrosarcoma is the most described, despite being a rare malignant neoplasm. It is a tumor histologically defined as a proliferation of dense mesenchymal fusiform cells with hypervascularized areas, showing considerable clinical similarity to tumors and vascular malformations. Clinically, they manifest themselves as fast-growing masses that occupy soft tissues and evolve with bleeding[26].

Myxofibrosarcoma is the myxoid variant of malignant fibrous histiocytoma, described as a rare malignant mesenchymal tumor of soft tissues. Clinically, it presents as a pleomorphic mass of myxoid stroma, painless and slow-growing[14]. The histopathological study of the lesion allows diagnosis and staging by visualizing the proliferation of the myxoid stroma with pleomorphic cells and curvilinear vessels[27]. Another rare tumor, which has around 40 cases described in the literature, the papillary intralymphatic angioendothelioma, is a vascular neoplasm observed in soft tissues, frequently in the derme, but also deep tissues such as the spleen, testicle, and tongue[28].

Our study has compiled the findings of six publications that have addressed the topic of interest over the last ten years, resulting in one retrospective study, three case reports, and two case series. From this number of findings, it is evident that there is a limited amount of publications with a high level of evidence related to the prevalence of non-cutaneous soft tissue tumors and pseudotumors in the feet or ankle in Brazilian health services. The stimulation to study these neoplasms is fundamental to improving the knowledge that helps clinical practice, accelerates diagnosis, and promotes early treatment, aiming for greater chances of cure.

Conclusion

In the last ten years, in Brazilian health services, the following non-cutaneous soft tissue tumors and pseudotumors in the foot or ankle have been reported: unspecified soft parts sarcomas, giant cell tumors, synovial chondromatosis, fibromatosis, synovial sarcoma, liposarcoma, undifferentiated pleomorphic sarcoma, congenital infantile fibrosarcoma, papillary intralymphatic angioendothelioma and myxofibrosarcoma. There have been more reports of malignant tumors than benign tumors. However, this finding does not necessarily reflect the Brazilian epidemiological reality, but it may represent a view in which resected benign tumors and pseudotumors are often not sent for anatomopathological study or reported in the literature. Moreover, there is a notable scarcity of Brazilian publications addressing the topic. International literature guides the epidemiological, diagnostic, and therapeutic understanding of these neoplasms in the feet and ankle. However, Brazilian epidemiologic studies with higher levels of evidence are crucial for grounding the Brazilian orthopedist's approach and clinical decisions.

Authors' contributions: Each author contributed individually and significantly to the development of this article: GSB *(https://orcid.org/0000-0003-1753-2655), and VHMR *(https://orcid.org/0000-0003-0154-7385) Conceptualization, data curation, formal analysis, investigation, methodology, validation, visualization, writing – original draft, writing – review & editing; EASJ *(https://orcid.org/0000-0002-5054-874X) Conceptualization, data curation, formal analysis, investigation, methodology, project administration, supervision, validation, visualization, writing – original draft. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Systematic Review

Relationship between foot and ankle tendinopathies and dyslipidemia: a literature review

Pedro Luís Ortelani Valadares[1], Maria Amália Garcia da Silveira Araújo[1], Isadora Maria de Souza e Silva[1], Caroline Magrini Turini[1], Anna Luiza de Araújo Ribeiro[1], Anna Cláudia Ferreira Nunes[1], Eli Ávila Souza Júnior[1]

1. Universidade Federal de Alfenas, Alfenas, MG, Brazil.

Abstract

Objectives: Dyslipidemia is a multifactorial condition related to genetic factors, dietary patterns, sedentary habits, and socioeconomic conditions. Foot and ankle tendinopathies are a common problem in orthopedic consultations and can represent up to 30%, highlighting some risk factors, such as metabolic disorders.

Methods: This study is an integrative review of the literature addressing the correlation between foot and ankle tendinopathy and dyslipidemia. The keywords used were: "tendinopathy," "foot and ankle," and "dyslipidemia," with the operators "AND" and "OR" for the search. The following inclusion criteria were established: case reports, cohort studies, case and control studies, clinical trials, and biomechanical studies published between 2013 and 2024, indexed in the following databases: Pubmed (Medline), Scielo, Lilacs, and Scopus, published in English, Spanish, and Portuguese.

Results: Several mechanisms have been proposed to explain the correlation between tendinopathies and dyslipidemia, although there is still no absolute clarity; it was shown that the Achilles tendon is the main tendon affected in the foot and ankle, especially by xanthomas, which lead to an increase in the area size, causing pain, edema, difficulty in movement and changes in gait.

Conclusion: It is believed that females with dyslipidemia, elderly patients, and individuals with a body mass index below 18.5kg/m^2 are more prone to tendinopathies.

Level of evidence II; Diagnostic studies.

Keywords: Tendinopathy; Foot and ankle; Dyslipidemia.

Introduction

Dyslipidemia is a multifactorial condition related to genetic factors, dietary patterns, sedentary habits, and socioeconomic conditions[1,2]. This disease stands out due to its harmful effects on various body systems, including the musculoskeletal system[3-5]. In this case, tendons are frequently affected by injuries ranging from xanthomas[6] to tendinopathies[7]. However, the mechanisms underlying this relationship are not well elucidated yet[8]. It is believed that there are numerous actions of cholesterol in tendons, such as changes in the microenvironment, accumulation of cholesterol in the intertendinous matrix, and inflammatory lipid effects[9,10].

The consequences of hypercholesterolemia in the shoulder, knee, and hand diseases are well reported in the literature[11]. In energy-stored tendons such as the Achilles and the quadriceps femoris[12-14], it is believed that dyslipidemia has the potential to alter their functional and histological characteristics[15]. Some studies have demonstrated that the formation of xanthomas may be an initial clinical manifestation of familial hypercholesterolemia[16].

A study in Sweden with 120 volunteers, 60 individuals with Achilles tendinopathy, and 60 controls observed that patients with tendon pathology presented concomitantly with dyslipidemia, low HDL, and waist circumference bigger than the controls[17].

Study performed at the Universidade Federal de Alfenas, Alfenas, MG, Brazil.

Correspondence: Eli Ávila Souza Júnior. Alameda do Café, 401, Condomínio Floresta, Alfenas, MG, Brazil. **Email:** eli.junior@unifal-mg.edu.br. **Conflicts of interest**: none. **Source of funding:** none. **Date received:** May 28, 2024. **Date accepted:** April 24, 2024. **Online:** August 30, 2024.

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Foot and ankle tendinopathies are a common problem in orthopedic consultations[18] and can represent up to 30%[19,20], highlighting some risk factors, such as advanced age, metabolic disorders, and use of medications like corticosteroids and statins[21]. These impact the patient's quality of life, causing impairments in gait, work functions, and financial conditions, as they sometimes require complex treatment[22].

Through this literature review, the objective of the study is to discuss and highlight the relationship between dyslipidemia and foot and ankle tendinopathies.

Methods

This literature review followed the steps of producing an integrative review, with the definition of the theme and objectives, choice of keywords and their use in the literature search, definition of inclusion and exclusion factors, selection of studies through the application of these factors, data collection, analysis of the data obtained and their presentation in detail.

The literature search was guided by the question: "Is there a relationship between dyslipidemia and foot and ankle tendinopathies?" The guiding question was elaborated on using the PICO strategy. The keywords used were: "tendinopathy," "foot and ankle," and "dyslipidemia." Such descriptors were used with the operators "AND" and "OR" for the search.

The following inclusion criteria were established: case reports, cohort studies, case and control studies, clinical trials, and biomechanical studies published between 2013 and 2024, indexed in the following databases: Pubmed (Medline), Scielo, Lilacs, and Scopus, published in English, Spanish, and Portuguese and addressing the correlation between foot and ankle tendinopathy and dyslipidemia.

Among the exclusion criteria were articles that did not explore feet and/or ankles and articles without reference to the context of lipidic changes.

The search strategy used for this research is summarized in figure 1, as recommended by the PRISMA guidelines.

Aiming to reduce possible interpretation biases, two researchers analyzed the articles independently, selecting them based on the inclusion and exclusion criteria. Subsequently, the selection results of each researcher were compared. Selection differences were resolved through discussion between the two researchers and a third researcher. The articles were classified according to the level of scientific evidence, according to the Agency for Healthcare Research and Quality (AHRQ).

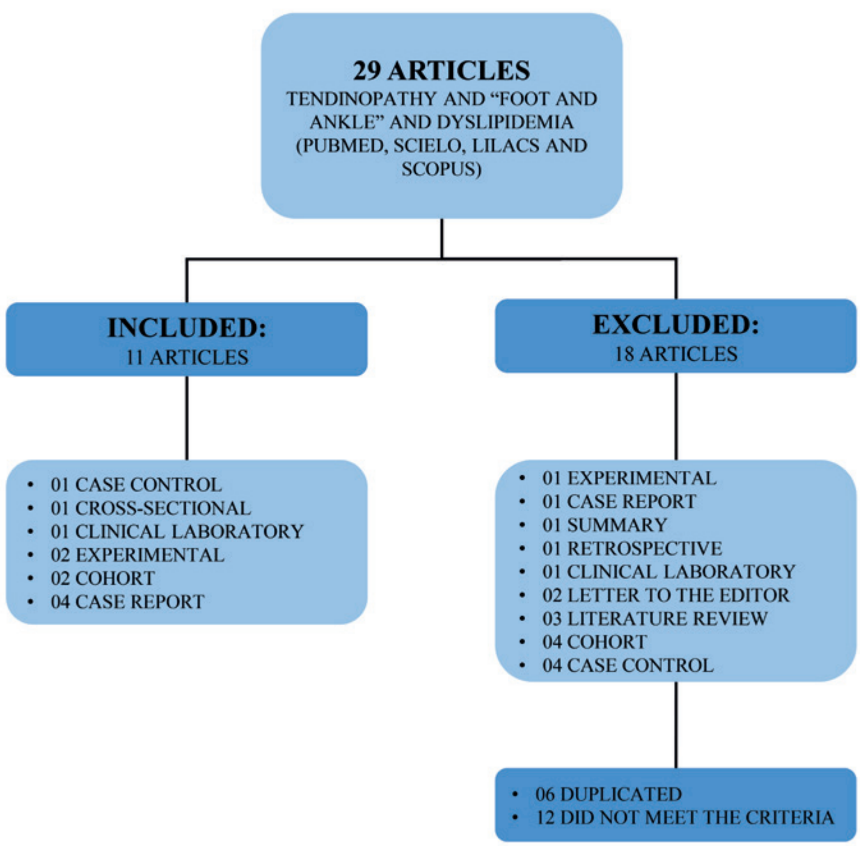

Figure 1. Systematization of articles analyzed according to the inclusion criteria.

The results were analyzed through table 1, which characterizes the publications according to authors, year of publication, type of study, objectives, and main results.

Results and discussion

The relationship between the prevalence of xanthomas, benign tendon tumors, and dyslipidemia has already been explored by many authors. Fernandes et al.[23] presented a report of a xanthoma in the Achilles tendon in a patient with a serum level of 268 mg/dL at the expense of LDL. Song et al.[24] presented another case of multiple xanthomas affecting the Achilles tendon bilaterally, hands and knees, in a 34-year-old patient with primary hyperlipidemia (233 mg/dL of total cholesterol), being treated with statins. The patient also had decreased Achilles and patellar reflexes and pain on palpation of the tendons, especially in the right lower limb[24]. The magnetic resonance imaging identified abnormalities in the Achilles, anterior and posterior tibial tendons, and peroneus longus tendons on the right. Histopathological examination of the lesions showed macrophages full of lipids. It is believed that the lesions are formed in response to an inflammatory reaction triggered by hypercholesterolemia in the tissue environment[24]. Another report by Roy et al.[25] exposed a multinodular condition, identified in the histopathological report as an extensive tuberous xanthoma, in a patient with previously unidentified familial hypercholesterolemia. The patient had abundant edema around the knee, elbow, ankle, and small joints of the feet, in addition to visible thickening and enlargement of the Achilles tendons in both lower limbs[25].

In a clinical trial developed by Li et al.[7], cells from murine models exposed to significant cholesterol levels (10 mg/dL) were used, and their behavior was evaluated. The study proved that cholesterol interrupted cell migration, proliferation, and division, in addition to inducing apoptosis and autophagy in tendon-derived stem cells. It is believed that such events occur through mechanisms such as producing reactive oxygen species, hyperactivation of cleaved caspase-3 and BAX, reduction of Bcl-xL expression, and accumulation of CL3-II. In this sense, the affected cells play an important role in the pathology of tendinopathy, and it is believed that this is one of the mechanisms by which dyslipidemia is related to tendinopathies, given that high cholesterol levels increase the risk of pain and rupture of the tendons[7].

Another experimental study by Grewal et al.[15], using ApoE-KO mice, whose objective was to visualize structural changes in tendons after a controlled lipid diet, did not demonstrate any cellular deformities. As a result, it was expected to visualize a

Table 1. Analysis of articles found in databases according to indexers and search criteria.

Author	Year of publication	Types of studies	Objective	Main results
Fernandes et al.	2015	Case report	Early diagnosis of tendon xanthomas is essential	Imaging diagnosis is faster
Grewal et al.	2013	Experimental study	The knock-out mice with dyslipidemia and involvement of tendon	The results were clarified in another study
Kwak et al.	2023	Cohort study	Treatment of dyslipidemia and the development of tendinopathy	The use of statin favors the development of tendinopathies
Kutkiene et al.	2019	Case-control study	Achilles tendon ultrasound in identifying an increased risk for dyslipidemia	Ultrasonography of the Achilles tendon revealed tendinopathy
Song et al.	2015	Case report	Elucidate that tendon xanthomas may be clinical manifestations of dyslipidemia	Diagnosis of dyslipidemia and xanthomas in lower limbs
Li et al.	2020	Clinical laboratory study	Analyze whether high serum cholesterol levels have biological effects on tendon-derived stem cells	Dyslipidemia induces apoptosis and autophagy of tendon-derived stem cells
Ahn et al.	2021	Cohort study	Evaluate the correlation between dyslipidemia and the risk of tendinopathy	Dyslipidemia is associated with a risk of tendinopathy and Achilles tendon rupture
Albers et al.	2016	Cross-sectional study	The incidence and prevalence of lower limb tendinopathy	Tendinopathy is associated with dyslipidemia
Waugh et al.	2023	Experimental study	The knock-out mice with dyslipidemia and involvement of tendon	The increased cholesterol alters the biomechanical properties of the Achilles tendon
Roy et al.	2020	Case report	Demonstrate that tendon xanthomas are clinical signs of familial hypercholesterolemia	A previous diagnosis of dyslipidemia, with numerous lipid deposits and thickening of the Achilles tendon
Corredoira et al.	2024	Cross-sectional study	To analyze the size of tendon xanthomas in the Achilles tendons of individuals with familial hypercholesterolemia	The tendon xanthomas have varied characteristics depending on age, sex, and LDL cholesterol concentration

change in the architecture of the tendons and high cellularity of rounded tenocytes when compared to normal tendons; however, instead of presenting Achilles tendons with wavy, discrete, and band-shaped deposits under microscopy, no changes were observed[15]. Contradictorily, a more recent trial by Waugh et al.[12], using wild-type mice and also knock-out mice for apolipoprotein E, demonstrated that even a small increase in cholesterol is capable of causing biomechanical changes in tendon structures, therefore, causing a risk of injury. According to Waugh et al.[12], the negative result in ApoE mice can be justified by the inadequacy of this biological model, given that these animals have a subtendon and, therefore, the expected changes cannot be visualized[12].

Epidemiological factors demonstrate a higher prevalence of tendinopathies related to dyslipidemia in females. A case-control study by Kutkienė et al.[26] evaluated 2013 patients, of which 110 already had a previous diagnosis of dyslipidemia. The study analyzed the prevalence of Achilles tendinopathy in 42.7% of patients with severe hypercholesterolemia. When analyzing the prevalence by sex, the association between dyslipidemia and tendinopathies was greater in females[26].

Corredoira et al.[6] published a cross-sectional study including 377 patients diagnosed with familial hypercholesterolemia, in which demographic data such as age, sex, low-density lipoprotein cholesterol, and lipoprotein (a) cholesterol levels were analyzed, together with ultrasound data on the maximum thickness of the Achilles tendon. The results demonstrated that tendon xanthomas, a characteristic of familial hypercholesterolemia, are related to exposure to high cholesterol levels and individual variability, with inert factors responsible for 20% of the heterogeneity of cases[6]. A cross-sectional study by Albers et al.[22] conducted in a Dutch population evaluated the prevalence of lower limb tendinopathy and identified a greater correlation between older individuals and those with metabolic disorders[22]. Another cohort study by Ahn et al. (2021), using a population sample from the Republic of Korea, demonstrated an increased risk of Achilles tendinopathy and Achilles tendon rupture in low-weight patients (BMI < 18.5 kg/m^2), approximately 37% and 116% respectively, under the influence of high LDL cholesterol levels, while obese patients with high LDL levels having a considerably lower risk, presenting around 10% and 16% respectively[10].

Recent studies have also explored the influence of drugs used in the treatment of dyslipidemia and its relationship with tendinopathies. A cohort study by Kwak et al.[27] suggested that the use of statins, regardless of the type, is paradoxically associated with an increased risk of developing different types of tendinopathy, such as Achilles tendon tendinopathy and rupture when compared to non-users of the drugs; this risk, however, tends to reduce according to cumulative daily doses[27]. The report by Roy et al.[25] further infers that commonly prescribed statins may not be very effective in cases of homozygous familial hypercholesterolemia, making it ideal for the use of innovative therapies such as PCSK9 inhibitors or lomitapide[25].

Foot and ankle tendinopathies are a multifactorial condition that results from a complex interaction between intrinsic and extrinsic factors in the affected individual. Hypercholesterolemia is associated with tendon pathologies; however, the reasons behind this relationship are not yet fully understood. Among the studies chosen, the most explored were Achilles tendinopathies and their relationship with dyslipidemia. It was noted that female, elderly patients and those with dyslipidemia with a BMI below 18.5 kg/m^2 are more prone to tendinopathies, especially patients with a previous diagnosis of familial hypercholesterolemia, whether homozygous or heterozygous.

Understanding the relationship between dyslipidemia and foot and ankle tendinopathies is crucial for developing more effective early diagnosis, prevention, and treatment strategies. The studies included in this review emphasize the applicability of ultrasound examination to visualize tendon xanthomas, initially because it is an accessible diagnostic tool widely distributed in health units. Interventions to control dyslipidemia, such as lifestyle modifications and appropriate drug therapy, can play an important role in the prevention and management of this condition; therefore, all variables in this relationship must be evaluated with caution. The use of drugs from the statin class, used to reduce serum LDL levels, does not necessarily result in a reduced risk of developing tendinopathies; on the contrary, paradoxically, they can constitute an additional risk factor.

Conclusion

Several mechanisms have been proposed to explain the correlation between tendinopathies and dyslipidemia, although there is still no absolute clarity; it was shown that the Achilles tendon is the main tendon affected in the foot and ankle, especially by xanthomas, which leads to an increase in the size of the tendon, causing pain, edema, difficulty in movement and changes in gait. It is believed that females with dyslipidemia, elderly patients, and individuals with a BMI below 18.5kg/m^2 are more prone to tendinopathies.

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Original Article

Shock wave therapy in foot and ankle nonunion fractures: case series

Gabriella de Figueiredo Rodrigues[1], Jefferson Soares Martins[1], Ana Raquel Nascimento Lawall[1], Salyme El Kadi[1], Allyson Cândido de Abreu[1], Alex Barbosa Almeida[1], Lucas Soares Teixeira[1], Lucas Ricci Delevedove[1]

1. Hospital de Urgências de Goiânia, Goiânia, GO, Brazil.

Abstract

Objective: Report a case series of five patients with foot and ankle nonunion fractures treated with radial-type extracorporeal shock wave therapy.

Methods: This retrospective study described the evolution of five patients diagnosed with foot and ankle nonunion fractures, radiologically and clinically, treated with radial shock wave therapy, admitted from September 2021 to August 2022 with outpatient follow-up.

Results: After the stipulated treatment sessions, all patients showed radiographic signs of bone callus, with improved pain and good functional results. Comprehensively, treatment with radial shock waves for foot and ankle nonunion fractures was effective and did not require intervention.

Conclusion: Radial-type shock wave therapy, especially in places of greater bone prominence, seems effective in treating nonunion fractures, exposing the patient to a lower risk of complications than surgical treatment.

Level of Evidence IV; Therapeutic Study; Case Series.

Keywords: Pseudarthrosis; Fractures, bone; Foot; Extracorporeal shockwave therapy.

Introduction

Extracorporeal shock wave therapy (ESWT) was initially applied to treat ureteral lithiasis, such as lithotripsy, and over time, they observed a possible effect on osteogenesis[1-3]. The use of ESWT in orthopedics included treating inflammatory soft tissue conditions, tendinopathies, avascular necrosis of the femoral head, and nonunion[1].

The shock wave is a three-dimensional kinetic energy pulse of high amplitude and short microseconds duration, which can be generated by different means, transforming electrical energy into mechanical energy[1,2,4]. It is classified according to the density of the energy flow in relation to the direction of propagation, low or high energy, and the type of wave, focal or radial[1].

Focal shock waves are generated by unique acoustic pulses generated by a sparkler (electro-hydraulic principle), similar to a speaker (electromagnetic principle), while radial shock waves come from a mechanism similar to ballistics, in which compressed air or a magnetic field launches a pulse in a tube until it reaches the wave applicator on the skin, which converts the stress waves into pressure waves[1,5].

Radial waves tend to be lower energy, do not require anesthesia for application, and are cheaper than focal waves[1]. They also have more consistent effects on tissue dissipation than focal waves if they encounter obstacles such as calcifications or bone tissue[5].

The application is performed by placing the device on the injury topography to treat the skin perpendicular to it. The practicability varies according to the wave type, application time, and number of sessions. These factors are still being studied to define and specify the best treatment according to the diagnosis and the effectiveness of the type of shock waves to be used[6].

Study performed at the Hospital de Urgências de Goiânia, Goiânia, GO, Brazil.

Correspondence: Gabriella de Figueiredo Rodrigues. Avenida 31 de Março, s/n, Av. Pedro Ludovico, Goiânia, GO, Brazil. **Email:** gabriellaortopedia@gmail.com
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Focal waves are widely used due to their greater intensity and tissue penetration and can reach the tissue to be treated between 0.5 and 5 cm deep. Radial waves, which were used in this study, have a lower penetration, causing less tissue damage and reaching more superficial tissues between 0.5 and 1.5 cm[3].

Extracorporeal shock wave therapy affects the production of microfractures in the sclerotic bone ends, forming a subperiosteal hematoma of the cortical bone and stimulating neoangiogenesis and bone consolidation[1]. Shock waves also indirectly affect bone tissue called a cavitation bubble, which consists of partial apoptosis of the osteocytes and production of osteoblasts[1,2,4,7,8]. In addition, low-energy shock waves stimulate progenitor and differentiated stem cells[3,7].

The main benefit of ESWT in bone tissue is mainly osteoblastic stimulation for osteogenesis and not just a mechanical action of periosteal detachment promoting bone consolidation[4]. Indications of ESWT also include soft tissue lesions, acting as a stimulus to increase the production of vascular endothelial growth factor in cartilage, nerve, and connective tissues, promoting angiogenesis and cell regeneration, and blocking the pain cascade[4,6].

Radial-type ESWT is easy to perform treatment in an outpatient setting, without analgesics and its potential risks of a surgical procedure, even though it may cause hematoma and mild pain during application[5]. On the other hand, the use of focal shock waves is usually performed under sedation or analgesics in a hospital environment, with greater cost and risk to the patient, and may cause greater soft tissue edema, fractures, intraosseous bleeding, and thromboembolism[1,2,4].

The presence of an epiphyseal plate or malignant tumor in the affected area, acute infection, and pregnancy are general contraindications for shock waves, with coagulopathy or use of anticoagulants being a relative contraindication for high-energy ESWT[1].

Extracorporeal shockwave therapy has been used in cases of nonunion fractures, a condition in which the fracture shows no sign of bone consolidation evolution on radiographic examination in the expected time. The presence of sclerotic edges, absent bone callus, and persistence of the fracture focus result in pain and instability[8,9].

In the scientific literature, most reports regarding the efficacy of ESWT in treating nonunion fractures refer to long bones and upper limbs and the use of focal waves, and data regarding the use of ESWT in foot and ankle nonunion fractures are scarce.

The objective of this study is to report a case series of five foot and ankle nonunion fractures treated with radial-type extracorporeal shockwave therapy.

Methods

The study was approved by the Institutional Review Board, and the Informed Consent Form was not necessary due to the unidentifiable data extraction, without the name or any data that would allow their identification. All patients admitted for treatment of nonunion fractures and under conservative treatment were included, and those using calcium or bone-forming medications or with previous use of bisphosphonates were excluded.

This study is a retrospective analysis of five patients admitted with foot and ankle nonunion fractures. Data regarding age, sex, elapsed fracture time, fracture site, comorbidities, and signs of consolidation after shock wave therapy were collected from the hospital's electronic medical record.

All patients were followed clinically and submitted to radiographs at all outpatient follow-ups at each ESWT session and after four weeks, eight weeks, and one year of treatment. During the ESWT sessions, the load was maintained with partial support from a robofoot. From the fourth session, all patients were released to full load with a robofoot for four weeks, as they presented good callogenesis, and the robofoot was removed after this period.

Descriptive analysis of patient data was performed using Microsoft Excel version 16.54 (2021) and IBM SPSS Statistics version 23 (2015).

Results

Five patients with foot and ankle nonunion fractures were admitted between September 2021 and August 2022, presenting an absence of bone consolidation, diastasis of the fracture focus, and complaints of pain.

All patients were submitted to four sessions of radial-type ESWT, performed on an outpatient basis, under the protocol of four sessions of 2500 shots per session, with an intensity of 1.5 to 3.0 bar and a frequency of 10 to 14 Hz, at a weekly interval between them, and comparative radiographs were performed after each session. At the end of this period, improvement in pain was reported by the patients, and good bone consolidation was observed on the radiographs, which were then released for full load. The patients maintained outpatient follow-up after treatment, showing the effectiveness of the treatment performed.

Females were the most prevalent (60%), the left side was the most affected (60%), and the mean age was 49.2 years (range 32 to 61 years), with a median of 55 years and a standard deviation of 11.9. The fractures were due to low-energy traumas, such as a rotational mechanism of the foot or ankle; all were closed type. The mean fracture time was 64.4 days, with a standard deviation of 38.81 (Table 1). Figure 1 shows the radiographic evolution of the patient with nonunion medial malleolus fracture before the first session and 1, 2, and 6 months of evolution.

Discussion

The discovery of the effect of focal-type ESWT on bone tissue dates back to 1991. Valchaneau et al.[10] initially described its applicability in treating delayed consolidation in fractures and pseudoarthrosis, demonstrating the efficacy of ESWT on osteogenesis stimulation by several mechanisms.

Table 1. Patient description

Patient	Sex	Laterality	Age	Fracture time	Place	Shock wave type	Number of sessions	Comorbidity	Signs of bone consolidation
1	Female	Right	42 years	42 days	Medial malleolus	Radial	4	No	Yes
2	Male	Left	32 years	30 days	5th metatarsal base	Radial	4	No	Yes
3	Female	Left	56 years	120 Days	5th metatarsal base	Radial	4	Kidney transplantation (chronic kidney disease)	Yes
4	Female	Right	61 years	40 days	5th metatarsal base	Radial	4	No	Yes
5	Male	Right	55 years	90 days	5th metatarsal base	Radial	4	No	Yes

Figure 1. Radiographs of nonunion fracture of the medial malleolus before and after shock wave therapy. (A) Before therapy; (B) four weeks after therapy; (C) eight weeks after therapy; (D) six months after therapy.

Since then, EWST has been used for several musculoskeletal pathologies, from soft tissue injuries (such as tendinopathies, epicondylitis, and fasciitis) to bone injuries, such as fractures without deviation and delayed bone consolidation. Currently, the study with radial waves has been enhanced to improve its applicability and ensure cost reduction and the decreased rate of side and tissue effects[5].

Wuerfel et al.[7] conducted a systematic review, including 180 studies published between 1988 and 2021, that addressed the ESWT effects on connective tissue and muscle/nerve tissue. The ESWT effect on bone and cartilage tissue was described in 100 studies published over 33 years, with most of the studies (64%) performed in animal models and the others in primary or secondary cell culture. The authors noted that ESWT still needs further studies to establish optimal treatment settings, intensity, duration, location, and applied energy, although it is a safe and effective treatment option for various musculoskeletal system pathologies.

In parallel with this study, Schmitz et al.[5] conducted a systematic review to evaluate whether ESWT would be an effective and safe non-invasive treatment option for tendons and other musculoskeletal system pathologies based on data from the Physiotherapy Evidence Database (PEDro). One hundred and six studies were included in the qualitative synthesis, from which the authors established the following statements, based on randomized clinical trials, about radial and focal ESWT. Extracorporeal shockwave therapy is effective and safe, but the application of local anesthesia and insufficient energy negatively affects the outcome. No scientific evidence of the results using radial or focal ESWT was observed. The ideal treatment protocol for ESWT appears to be three treatment sessions at one-week intervals, with 2,000 shots per session and the application of the highest possible energy flux density.

Yue et al.[6] presented a case report of delayed mid-clavicle fracture consolidation and highlighted the use of focal waves in treating nonunion due to its dangerous side effects, mainly due to the proximity of the clavicle to vital organs, such as the lung. However, radial waves, in addition to presenting superficial adverse reactions, present cell proliferation, and similar results, compared to the configuration of focal waves, with greater capacity to induce angiogenesis, improving tissue perfusion. In superficial musculoskeletal disorders, greater pain relief was observed.

Tam et al.[11] investigated the effect of shock waves on cells extracted from the normal human periosteum to study possible response mechanisms and determine optimal treatment settings. The authors observed that ESWT can promote biochemical changes in periosteal cells and that lower doses, applied with a greater number of shocks and sessions, are more favorable to stimulating the activity of periosteal cells, inducing greater cell proliferation, with more viable cells, greater calcium deposit, and fewer side effects.

Kwok et al.[1] presented a broad review of ESWT in treating foot and ankle nonunion fractures. Among the eight studies evaluated, there was consolidation of 61 of the 65 metatarsal fractures (93.8%), 12 of the 13 ankle fractures (92.3%), and two talus fractures (100%), except for a single navicular fracture. The consolidation rate in the radial shockwave used in nine types of fractures was 77.8%, and in the focal shockwave, in 57 fractures, 94.7%. In the other 14 fractures reported in the studies, the type of shock waves was not specified. The efficacy of shock waves as a treatment choice for non-union fracture was demonstrated, but it proved to be unsatisfactory when comparing wave types due to the discrepancy in the sample.

Furia et al.[12] compared intramedullary screw fixation and high-energy shockwave treatment for pseudoarthrosis in the metaphyseal-diaphyseal region of the 5th metatarsal. Among the patients in the shockwave group, 86.9% were successful in the treatment, and in the fixation group, 90%. Regarding complications, only one patient in the ESWT group presented petechiae. On the other hand, for the 11 patients in the fixation group, one patient with refracture, one with cellulitis, and nine symptomatic hardware were identified. Thus, it was concluded that both treatments were effective. However, surgical treatment is more often associated with complications that result in a surgical reapproach.

Alkhawashki[13] used ESWT in the treatment of nonunion fractures in 44 patients (49 bones), with fractures in the femur and tibia and a single treatment session in 39 fractures. Consolidation was successful in 75.5% of cases at a mean time of 10.2 months. In cases where ESWT was unsuccessful, a gap of more than 5 mm, instability, vascularization impairment, and low-grade deep infection were observed.

Similar to our study, Kertzman et al.[14] also described the lack of substantial evidence using radial shockwave therapy in the treatment of nonunion fractures and performed the analysis of this treatment in 22 patients for nonunion fractures in superficial bones (including tibia and foot and ankle bones), despite previous surgical fixation in most cases. A protocol was performed with three weekly radial sessions with 3000 pulses each. Patients were followed clinically and radiologically, with treatment success in 73% at six months, with no side effects. It was concluded, therefore, that radial ESWT seems to be an effective and safe alternative in the management of nonunion fractures of superficial bones if diagnosed early.

Another more recent and valuable study, also published by Kertzman et al.[14], presented the largest prospective case series of radial shock waves and observed that both focal and radial waves influence osteoblast stimulation, good quality callogenesis, and resistance. The authors demonstrate that the use of this treatment is effective and safe and that, despite the idea that radial waves are superficial, there are studies that demonstrate that they can reach up to 4 cm in depth. They also exposed that many *in vitro* and animal studies have proven the ability of ESWT to stimulate consolidation, as seen in the study by Ramesh et al.[15], with the stimulation of chondrocyte production and bone growth in growth plates.

Our study reports a case series of five patients with ankle and/or base of the 5th metatarsal nonunion fractures presenting local pain. Shock wave treatment was applied as the treatment of choice for bone consolidation due to its less invasive methodology, and the radial wave type was used for its lower side effects in soft tissues. Despite the small sample size, all patients presented good clinical and radiological results after the fourth shockwave session, thus demonstrating that the method is effective, minimally invasive, and safe, with high chances of success.

As in the case reports described by Yue et al.[6] and Kertzman et al.[14], it can be suggested the efficacy of the radial wave in anatomically more superficial bones, with only subcutaneous coverage, such as clavicle and foot and ankle bones. Satisfactory bone consolidation was observed without complications that could exist if a more invasive surgical procedure and bone graft removal were used. Extracorporeal shock wave therapy should be considered for patients with clinical comorbidities who have contraindications to surgical treatment, such as patients in our report who had chronic kidney disease.

Conclusion

Radial-type shock wave therapy, especially in places of greater bone prominence, seems to be effective for treating nonunion fractures, exposing the patient to a lower risk of complications compared to surgical treatment. More robust studies with better and more compatible methodological designs are necessary for developing and specifying ideal treatment configurations, with a greater possibility of early and safe functional rehabilitation.

Authors' contributions: Each author contributed individually and significantly to the development of this article: GFR *(https://orcid.org/0000-0003-4979-7826) Conceived and planned the activities that led to the study, participated in the review process, data collection, survey of the medical records, formatting of the article and approved the final version; JSM *(https://orcid.org/0000-0003-4742-1905) 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, statistical analysis, bibliographic review, survey of the medical records, formatting of the article, clinical examination and approved the final version; ARNL *(https://orcid.org/0000-0002-0715-6417) Conceived and planned the activities that led to the study, interpreted the results of the study, articipated in the review process, data collection, statistical analysis, bibliographic review, survey of the medical records, formatting of the article and approved the final version; SEK *(https://orcid.org/0000-0003-3132-924X), and ACA *(https://orcid.org/0000-0002-9983-1888) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, data collection, statistical analysis, bibliographic review, survey of the medical records, formatting of the article and approved the final version; ABA *(https://orcid.org/0009-0009-3962-4025), and LST *(https://orcid.org/0009-0009-5170-7608) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, data collection, statistical analysis, bibliographic review, survey of the medical records, formatting of the article and approved the final version; LRD *(https://orcid.org/0000-0002-3830-0848) conceived and planned the activities that led to the study, bibliographic review and approved the final version. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) .

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Original Article

Preliminary results of acute Achilles tendon rupture treated with platelet-rich plasma and immobilization

Jorge Batista[1], Agustin Quesada[2], Hélder Miguel Duarte Pereira[3,4,5], Leandro Casola[6], Germán Matías-Joannas[6], Guillermo Arrondo[6]

1. Centro Artroscopico Jorge Batista, CABA, Buenos Aires, Argentina.
2. Instituto de Ortopedia y Traumatología, San Juan, Argentina.
3. Orthopaedic Department, Centro Hospitalar Póvoa de Varzim, Vila do Conde, Portugal.
4. Ripoll y De Prado Sports Clinic: FIFA Medical Centre of Excellence, Murcia-Madrid, Spain.
5. University of Minho ICVS/3B's – PT Government Associate Laboratory, Braga/Guimarães, Portugal.
6. Instituto Dupuytren, CABA, Buenos Aires, Argentina.

Abstract

Objective: Evaluate preliminary functional results, return to sport, re-rupture rate of acute Achilles rupture treated with one application of platelet-rich plasma (PRP), and immobilization.

Methods: A prospective analytical study was performed in patients with acute Achilles tendon rupture treated conservatively, associated with a single local application of PRP within 10 days of injury. The sample comprised 28 patients diagnosed and monitored by the same team for a minimum of 12 months. The American Foot and Ankle Society Functional Rating Scale (AOFAS), Achilles tendon total rupture score (ATRS), visual analog scale (VAS), and Achilles tendon resting angle (ATRA) were evaluated, the time of return to sports activities and isokinetic strength were evaluated at the different follow-up times and injury site using magnetic resonance imaging.

Results: The variance analysis of the AOFAS, ATRA, and VAS scores showed a significant difference at six and 12 months regarding the initial score and according to the injury site. The mean time to return to sports activities was 197 days, 85.7% had homogeneous tendons, and heel-rise type 2 was achieved in 28.6% at six months and 60.7% at 12 months.

Conclusion: The protocol proposed by our study for Achilles tendon rupture significantly improved all the scores evaluated compared to the initial condition and the isokinetic evaluations, obtaining even better results in proximal injuries.

Level of Evidence IV; Therapeutic studies investigating the results of treatment; Case series.

Keywords: Platelet-rich plasma; Achilles tendon; Bloodless medical and surgical procedures; Therapeutic treatment.

Introduction

The Achilles tendon is the strongest in the human body; however, ruptures are frequent in both elite and recreational athletes[1,2]. The exact cause of Achilles tendon ruptures is unknown because most patients who suffer a spontaneous rupture never had any symptoms before the rupture, although, studies on Achilles tendon ruptures show that almost all of these subjects have clear degenerative changes, such as hypoxia and mucoid degeneration, poor vascular supply, tissue and cell necrosis, calcification and lipomatosis, and irregular and degenerated collagen fibers[3].

Multiple studies have evaluated the efficiency and complications of treatments for Achilles ruptures. Over time, the "gold standard" for managing this injury has evolved from conservative approaches involving immobilization and functional rehabilitation to various surgical techniques developed over the years. Given the frequency of this injury, controversies remain as to whether its treatment should be surgical or nonsurgical[4].

Scientific evidence indicates a lower rate of re-rupture in surgical treatment, but with similar long-term functional results, with the advantage of nonsurgical treatment of not presenting the complications associated with surgery[3,4,5].

Study performed at the Centro Artroscopico Jorge Batista, CABA, Buenos Aires, Argentina.

Correspondence: Leandro Casola. Maipú 853, C1006 Cdad. Autónoma de Buenos Aires, Argentina. **Email:** leandrocasola@hotmail.com. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** October 31, 2023. **Date accepted:** August 17, 2024. **Online:** August 30, 2024.

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Achilles tendon ruptures are noted for their slow healing process, sometimes preventing an optimal restoration of strength and function to pre-injury levels and delaying the return to sports activity at acceptable times[6]. This issue could be due to the tendon's anatomy, as the proximal and the distal regions are well-supplied by the posterior tibial and peroneal arteries, while the medial portion has the least blood supply and is, therefore, the most challenging to regenerate[7].

When choosing the right treatment, it is important to consider the tendon healing process. Tendon healing usually involves the contribution of cells from multiple sources, primarily in the acute phase of rupture (first 2 weeks of injury), including infiltrating inflammatory cells, tendon surface resident fibroblasts, and tendon- or marrow-derived mesenchymal stem cells. Recent evidence suggests that modulating inflammation early after tendon repair may lead to better healing. It is important to recognize that while inflammation largely benefits tissue repair, excessive or persistent inflammation can be harmful. Inflammatory cytokines attract fibroblasts to the repair site, but excessive inflammation can lead to poor clinical outcomes[7].

Based on the published results, we understand that new techniques are necessary to accelerate these processes, improve healing speed, and return to sports activities.

Platelet-rich plasma (PRP) is used in multiple fields of medicine, particularly in numerous pathologies within orthopedics and traumatology, with its best results in muscle-tendon injuries (Figure 1)[8].

The objective of this study is to evaluate the preliminary functional results, return to sports activities, re-rupture rate of acute Achilles rupture treated with one application of PRP, and immobilization.

Methods

A prospective analytical study was performed in patients with acute complete and partial Achilles tendon ruptures submitted to nonsurgical treatment with walker boot immobilization for six weeks with 2 cm heel enhancement (2 heel pads of 10 mm each), one week without weight-bearing, then partial weight-bearing with crutches, at third week the removal of one heel pad and at fifth week removal of the last heel pad and total weight-bearing, associated with a single local application of PRP within 10 days of injury. A dose of 5 ml of PRP was applied to the injury site visualized under ultrasound guidance (RegenKit® A-PRP, Regenlab SA, Le Mont-sur-Lausanne, Switzerland) (Figure 2).

The sample comprised 28 patients diagnosed and monitored by the same team for a minimum of 12 months. Baseline characteristics such as age, injury mechanism, risk factors for tendon rupture (use of statins, smoking, sedentary lifestyle, etc.), time from the injury to the start of treatment (application of PRP and immobilizer boot), return to sports activities and level of physical activity were recorded.

Magnetic resonance imaging (MRI) of the affected ankle was performed to verify the rupture site (proximal, medial, or distal) and at six and 12 months after the treatment to evaluate the tendon characteristics (Figure 3).

Figure 1. Autologous platelet-rich plasma kit, closed system (RegenKit® A-PRP, Regenlab SA, Le Mont-sur-Lausanne, Switzerland).

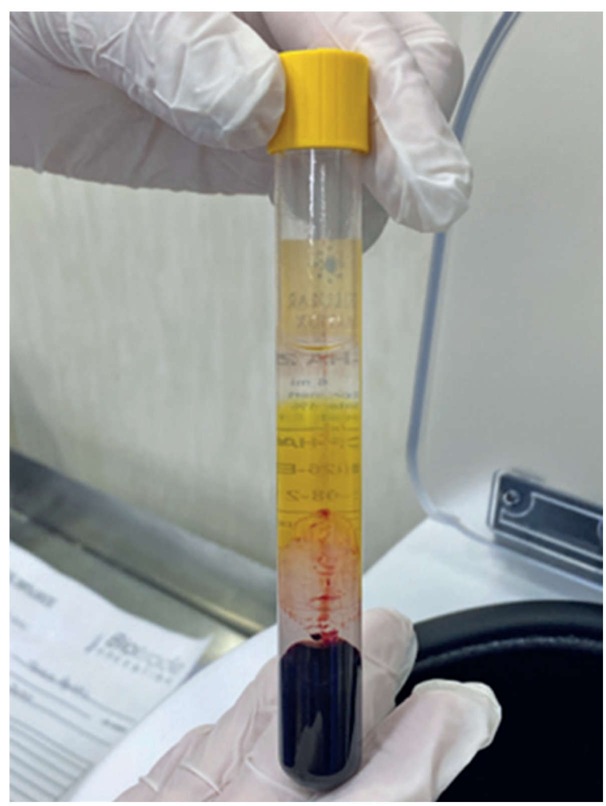

Figure 2. Application under aseptic conditions of 5ml of autologous PRP in the injury site under ultrasound vision.

The functional outcomes of the treated ankle were evaluated by validated scores: The American Foot and Ankle Society Functional Rating Scale (AOFAS), Achilles tendon total rupture score (ATRS), visual analog scale (VAS), and Achilles tendon resting angle (ATRA) (Figure 4).

The strength of the treated ankle compared to the healthy one was measured through an isokinetic evaluation. The heel-rise test was used to compare both sides and classify functionality as weak, mild positive (less than the healthy side), and normal (equal to the healthy side).

In the follow-up period, the tendon healing was evaluated with MRI (Figure 5). Before treatment, the injury site (proximal, medial, or distal) was classified according to the Chang classification[9], and at six and 12 months, the tendon condition was evaluated by assessing the presence of any gap, in addition to the homogeneity and heterogeneity of the tendon.

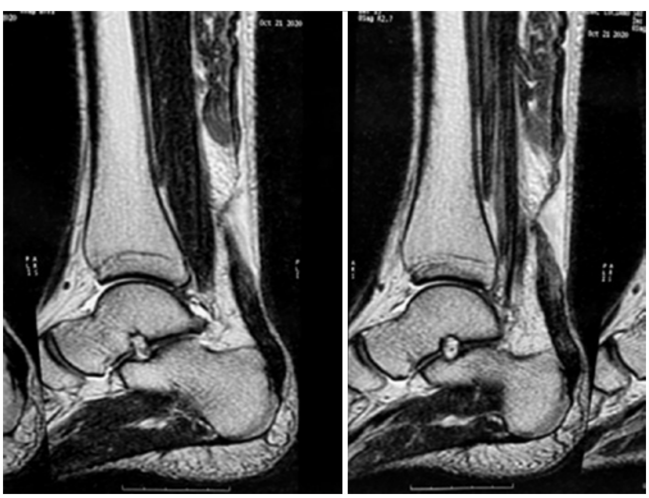

Figure 3. Magnetic resonance imaging (sagittal section) where a complete Achilles tendon rupture in its medial area is visualized.

The score differences, the time to return to sports activities, and isokinetic strength were evaluated at the different follow-up times and injury site (MRI) through variance analysis with mixed models (design of repeated measures) and the t-student test for paired samples. The time of evolution (initial, six, and 12 months) and injury site were defined as predictor variables. Homoscedasticity and normality were verified by graphical methods and with the Shapiro-Wilks test. Post-hoc comparisons between groups were obtained by Tukey's method.

The association between paired categorical variables with more than three categories was evaluated by Stuart Maxwell's marginal homogeneity test and Fisher's test in those not paired.

The tests with $p < 0.05$ and 95% confidence level were considered significant. Data analysis was conducted with R Studio statistical software (R core team, 2022).

Results

Table 1 summarizes the demographic, clinical characteristics, risk factors, times until the procedure, and return to sports activity.

Functional scales according to follow-up time

The variance analysis of the AOFAS, ATRA, and VAS scores showed a significant difference at six and 12 months compared to the initial score. As for the ATRS, the means increased significantly and progressively over the follow-up time. The data are shown in Tables 2 and 3. Comparisons between the different Tukey follow-up times revealed at what times these scales differ during follow-up. The p-values and magnitude of the effect are shown in Figure 6.

The isokinetic strength of the affected ankles compared to the healthy side at six months was contrasted with the strength at 12 months through a t-student test, revealing a statistically significant difference ($p < 0.001$). This comparison showed that the mean strength at six months was 7.1% to 13.2% lower than that recorded at 12 months (Figure 7).

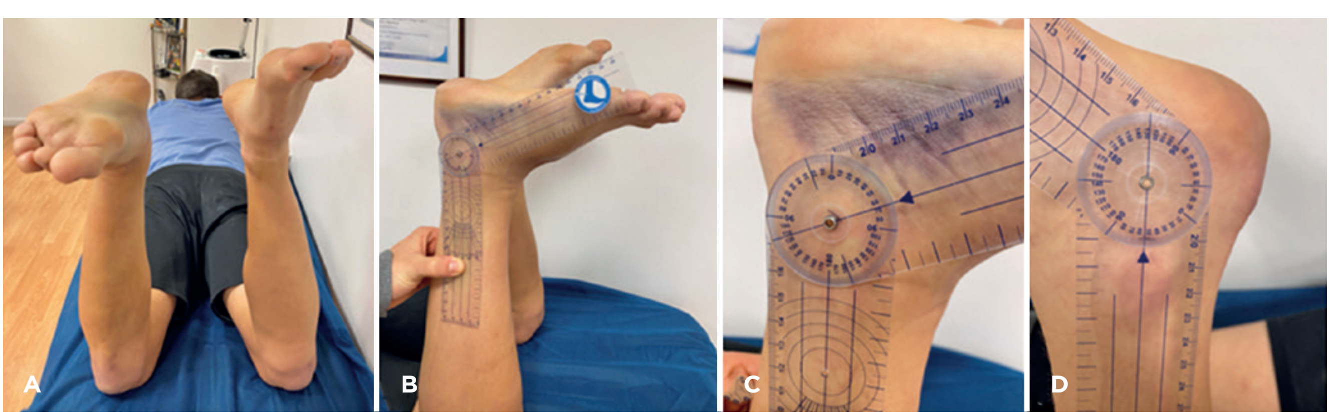

Figure 4. Achilles tendon rupture angle (ATRA) measurement images in patients with left Achilles tendon rupture.

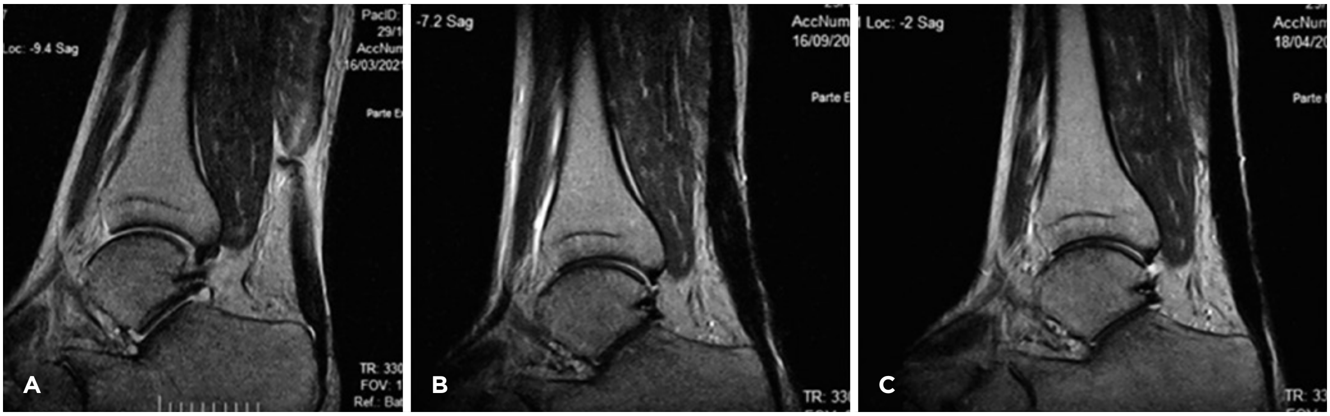

Figure 5. (A) Magnetic resonance imaging (sagittal section) where the Achilles tendon rupture in its medial area is visualized. (B) Image of the same patient six months after conservative treatment and PRP. (C) Image of the same patient at 12 months postoperative.

Table 1. General characteristics of the sample

	Overall (n = 28)
Age	
Mean (SD)	46.7 (11.6)
Median [Min, Max]	44.5 [26.0, 73.0]
Days from injury to infiltration	
Mean (SD)	4.21 (3.07)
Median [Min, Max]	3.50 [0, 10.0]
Return to sports activity in days	
Mean (SD)	197 (57.7)
Median [Min, Max]	177 [148, 439]
Risk Factors	
0	15 (53.6%)
1	8 (28.6%)
2	1 (3.6%)
3	4 (14.3%)
Level of physical activity	
Active	26 (92.9%)
Inactive	2 (7.1%)
Sex	
Male	25 (89.3%)
Female	3 (10.7%)
Laterality	
Right	16 (57.1%)
Left	12 (42.9%)

*Risk factors: smoking, overweight, hypothyroidism, use of statins drugs.

Table 2. Functional scales and Achilles tendon resting angle

	AOFAS	VAS	ATRS	ATRA	Isokinetic strength
Statistic F	566.72	118.37	861.13	70.63	47,997
p-value	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001

AOFAS: The American Foot and Ankle Society Functional Rating Scale; VAS: Visual analog scale; ATRS: Achilles tendon total rupture score; ATRA: Achilles tendon resting angle.

Table 3. Functional scores and isokinetic results

	AOFAS	ATRA	ATRS	Isokinetic strength
Preoperative	52.7 (7.68)	55.5 (8.02)	17.7 (5.16)	
6 months	91 (7.51)	46 (6.78)	86.5 (12.1)	-0.205 (0.105)
12 months	94 (7.09)	45.2 (7.1)	93.7 (8.07)	-0.104 (0.09)

AOFAS: The American Foot and Ankle Society Functional Rating Scale; ATRA: Achilles tendon resting angle; ATRS: Achilles tendon total rupture score.

Functional scales according to injury site and risk factors

The analysis of the marginal effects revealed a significant difference according to the injury site for AOFAS, VAS, and ATRS, showing better results in the group with proximal Achilles tendon rupture. No differences were found between patients with and without risk factors (Table 4). In the ATRA score, there was no significance for either variable. The p-values and effect magnitudes are shown in Figure 8.

Return to sports activities

The mean of return to sports activities was 197 days, with no significant difference in time according to the injury site ($p = 0.59$) and risk factors ($p = 0.48$).

Relationship between heel-rise and MRI findings

Differences in MRI findings of the injured ankle were evaluated at six and 12 months. At six months, only one patient did not present homogeneity (GAP), and 85.7% presented homogeneous tendons with some areas of heterogeneity, without clinical relevance (scores altered or pain). At 12 months, 89.2% had homogeneous and continuous tendons. The proportion of tendon functionality equivalent to the healthy side (Heel-rise type 2) was achieved at 28.6% at six months and 60.7% at 12 months. This difference was statistically significant in the Stewart-Maxwell test ($p = 0.024$).

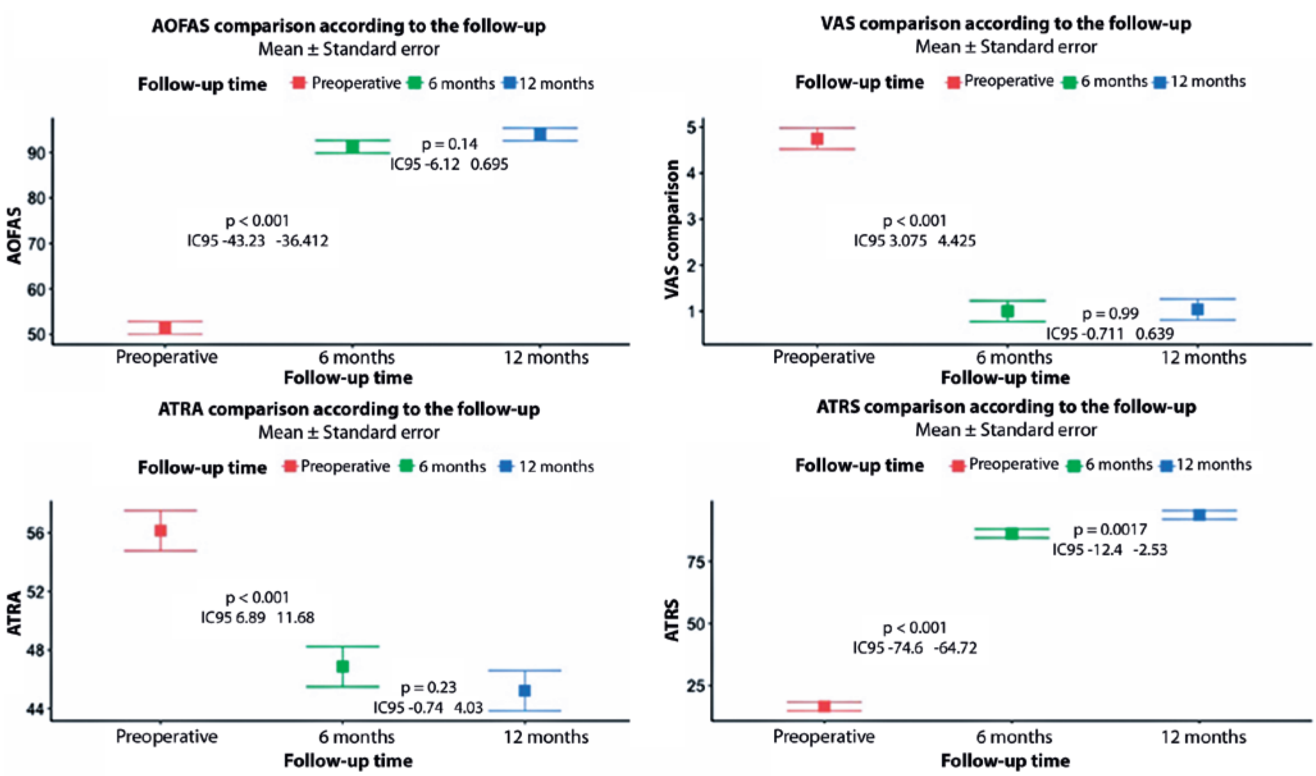

Figure 6. Scales comparisons according to follow-up time.

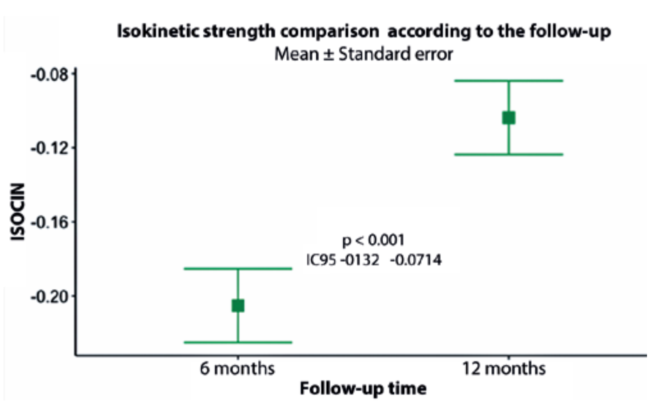

Figure 7. Isokinetic strength at six and 12 months.

Regarding the re-rupture incidence, there were two patients with type 2 injuries, without clinical relevance (Figure 9).

Although the functional and MRI studies were conducted at the initial, six and 12 months have been to date 39 months of evolution, and none presented relapses.

Discussion

The results of our study show that conservative treatment for proximal Achilles tendon ruptures improves functional scores compared to preoperative. In addition, strength and heel-rise improved significantly at six and 12 months.

Table 4. Association of risk factors with re-rupture

	OR	p-value
Sedentary lifestyles	0 (0 - 99.9)	0.99
Dyslipidaemia	3 (0.03 - 257)	0.45
High blood pressure	0 (0 - 29.7)	0.99
Overweight	7 (0.08 - 700)	0.24
Smoking	7 (0.08 - 700)	0.24
Hypothyroidism	0 (0 - 99.9)	0.99

Re-rupeture incidence = 0.06.
OR: Odds ration.

Surgical treatment of Achilles ruptures allows the re-rupture rate to decrease, but without differences in clinical scores or return to sport compared to conservative treatment[10].

Kauwe states that functional rehabilitation has reduced the risk of re-rupture in conservative treatment compared to the surgical approach. Because of this and the relatively high risk of complications associated with surgery, recent studies recommend conservative treatment. Kauwe also emphasizes that the rehabilitation protocol should be carefully managed in both treatment approaches to achieve a low re-rupture rate[11]. In our study, the same rehabilitation protocol was instructed to all patients, with a period of immobilization

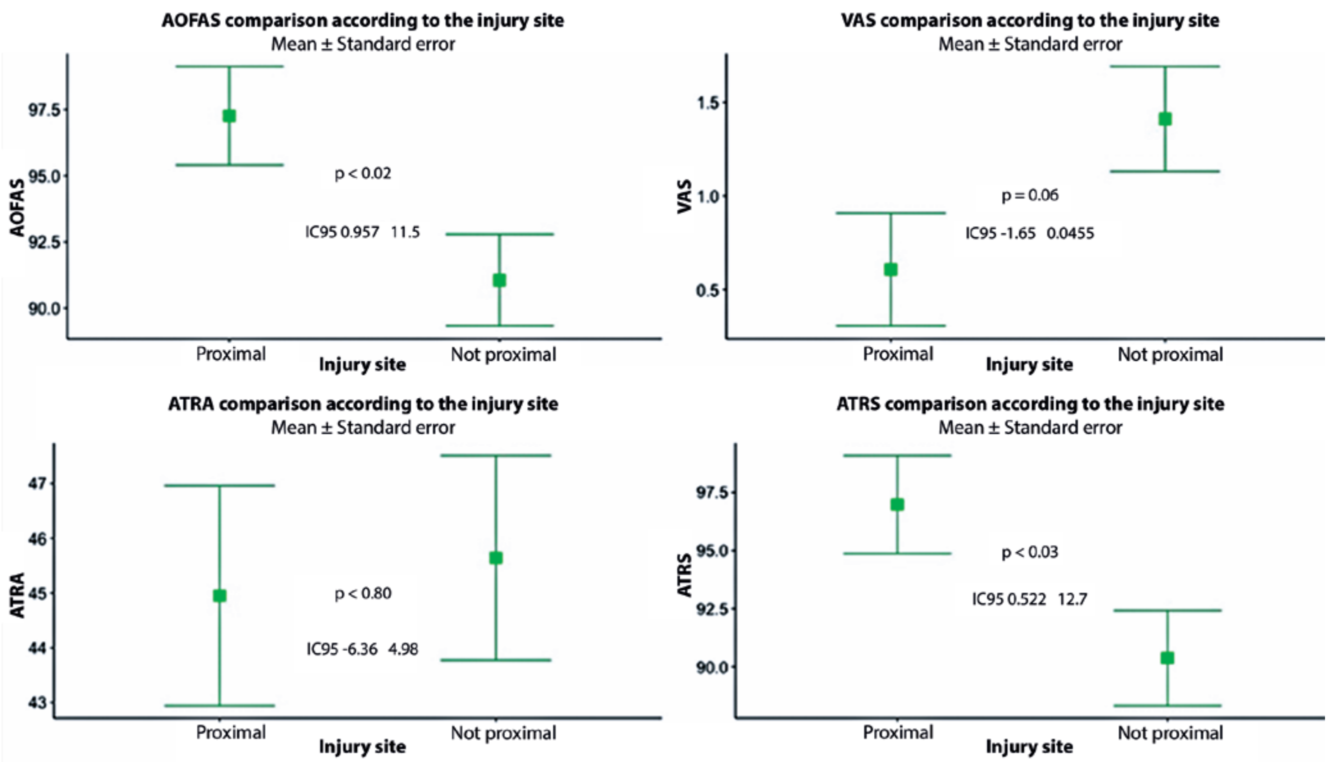

Figure 8. Scales at 12 months according to the injury site.

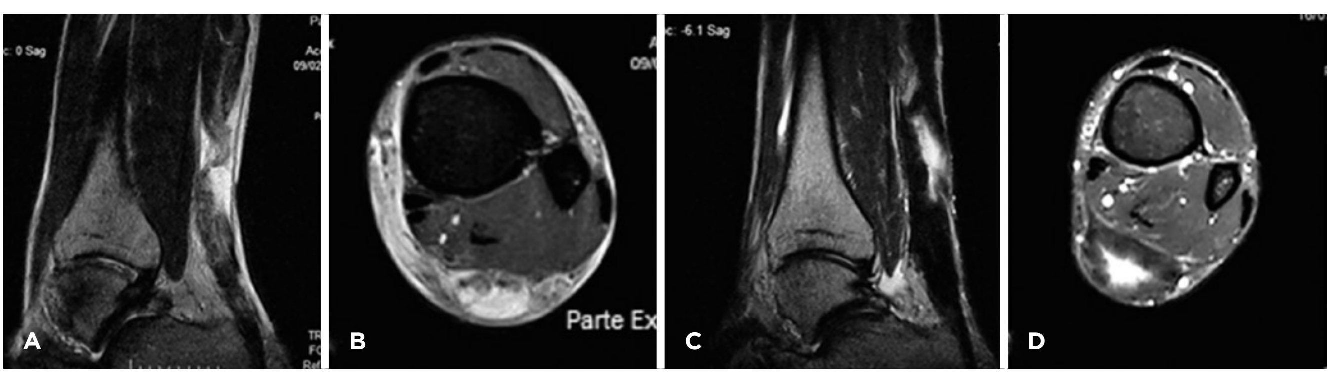

Figure 9. (A and B) Sagittal and axial sections of Achilles tendon rupture. (C and D) Focal images at the six months postoperative with no clinical relevance.

before functional rehabilitation, thus facilitating tendon healing.

A recent study analyzed the functional outcomes of conservative treatment for high Achilles tendon ruptures, reporting good functional results and a successful return to activity. However, the study also noted a statistically significant reduction in calf circumference in the injured leg compared to the healthy one, along with atrophy of the soleus muscle in the affected limbs. The strength tests improved significantly in our series at six and 12 months compared to the preoperative period. At six months, 28.6% of patients achieved muscle strength equal to the contralateral leg, and by 12 months, this increased to 60.7%, indicating an acceptable outcome within a relatively short period. This rapid improvement raises the possibility that the use of PRP may have contributed to the accelerated recovery, warranting further study.

There is little current evidence in the literature concerning PRP as a biological adjuvant and anti-inflammatory therapy. A recent study compared surgical and conservative treatment in groups with and without PRP and analyzed results, concluding that no clear data emerged regarding whether PRP would provide a benefit in treatment[12].

A recent meta-analysis, including six studies involving PRP therapy in Achilles ruptures, gathered 256 patients with PRP application, compared the results with 254 patients without PRP, and concluded no differences in the medium and long term. However, it does not clarify whether the injuries are proximal to the mid-third or insertional[13]. The data of the injury site is of utmost importance since proximal injuries, as described above, have better vascularization, and therefore, the effect of PRP could be more beneficial, unlike pure or more distal tendon injuries.

Despite the above, *in vitro* studies verify the effects of cell migration and expression of growth factors that would favor the regeneration of tendon tissue, as is the case of the Imai et al study[14].

This study has limitations, such as no randomization and the absence of a control group. However, due to no consensus on the treatment of these injury types, this study was considered appropriate as an attempt to reduce the re-rupture rates and elongations often associated with functional rehabilitation while reducing complications related to open or percutaneous treatment of acute Achilles tendon ruptures.

In addition, the procedure is technically simple, does not require a certain learning curve, and has a low cost in terms of Achilles tendon surgeries and their complications. Despite all the above, and to the best of our knowledge, this study is the first to describe the use of biological devices (PRP) in the treatment of acute Achilles tendon rupture with a minimum follow-up of 12 months.

Conclusion

The treatment protocol proposed by our study for Achilles tendon ruptures significantly improved all the scores evaluated compared to the previous condition, in addition to the isokinetic evaluations, obtaining even better results in proximal injuries. The results showed 89.2% homogeneous tendons at 12 months in the MRI evaluation, and only two patients had focal heterogeneous images, which had no clinical relevance. At 39 months of evolution, no patient presented re-ruptures. The analysis of these results allows us to continue investigating these injuries and their treatment with PRP as adjuvant biological therapy, with promising long-term results.

Authors' contributions: Each author contributed individually and significantly to the development of this article: JB *(https://orcid.org/0000-0003-0910-4140), and AQ *(https://orcid.org/0000-0001-5036-074X), and HMDP*, and LC *(https://orcid.org/0000-0003-1187-0864), Conceived and planned the activity that led to the study, wrote the article, participated in the review process. GMJ *(https://orcid.org/0000-0001-9998-190X), and GA *(https://orcid.org/0000-0003-4767-5489) Data collection, bibliographic review. All authors read and approved the final manuscript.*ORCID (Open Researcher and Contributor ID) iD.

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Original Article

Cuboid fracture: surgical treatment, midterm follow-up, and management algorithm

Fernando Vargas Gallardo[1], **Leonardo Lagos Sepulveda**[1], **Mauricio Parra Henriquez**[1], **Christian Urbina Bahamonde**[1], **Francisco Bravo Gallardo**[1], **Christian Bastías Soto**[1]

1. Foot and ankle Unit, Hospital Clínico Mutual de Seguridad, Santiago, Chile.

Abstract

Objectives: Describe the epidemiology of cuboid fracture, the mechanisms of injury and associated injuries, the progression to osteoarthritis, and propose a surgical management algorithm.

Methods: A retrospective and descriptive study of patients with cuboid fractures operated on between 2009 and 2014. The variables analyzed were age, sex, mechanism of injury, classification, associated fractures, and osteoarthritis changes, among others.

Results: Twenty-seven patients were included: 19 men and eight women. The mean age was 41.3 years (range 25 - 62). The mean follow-up was 3.3 years. The mechanisms of injury were motor vehicle accidents and falls from height. Among the patients, 44.4% had lateral column shortening, and 81.5% involved calcaneal cuboid articular surface. Cuboid locking plates were used in 15 patients, and single screw fixation was used in four patients. Three patients required a bone graft. Degenerative changes were observed in calcaneocuboid and cuboid-metatarsal joints.

Conclusions: Cuboid fracture is an uncommon injury. In general, the injuries are caused by high-energy accidents. In our study, 40.7% of patients had an injury to the medial column. It is recommended the use of a cuboid locking plate for comminuted fractures, screw fixation for simple fractures, and a bridging plate or external fixation can be considered for most complex cases.

Level of Evidence IV; Retrospective Case Series.

Keywords: Cuboid fracture; Internal fixation; Open reduction; Chopart injury.

Introduction

Cuboid fracture is an infrequent rare injury. In the United Kingdom, an annual incidence of 1.8/10,000 is reported[1]. Classically, there are two mechanisms of injury: compressive or "nutcraker" and distractive or avulsion injury. There are also isolated cuboid fracture cases reported in the literature[2-5]. Its occurrence can generate other consequences, such as foot lateral column shortening with a secondary flat foot[6].

The Orthopaedic Trauma Association (OTA) classification describes two types of cuboid fracture: simple and comminuted[7]. Generally, the literature supports the conservative treatment of the nondisplaced cuboid fracture[8]. On the other hand, different methods for managing displaced injuries or with articular involvement are described, and there is no clear consensus in the literature about these treatments[2,5,6,9-11].

The objectives of this study are to describe the epidemiology of cuboid fracture, the mechanisms of injury and associated injuries, the progression to osteoarthritis, and propose a surgical management algorithm.

Methods

A retrospective and descriptive study (case series) based on clinical records and image files. This study was approved by the Institutional Review Board.

The database of patients admitted to our institution who required surgery to manage a cuboid fracture was reviewed.

The imaging study consisted of pre-and postoperative radiographs in anteroposterior (AP), lateral (L), and oblique views of the affected foot and pre-and postoperative

Study performed at the Hospital Clínico Mutual de Seguridad, Santiago, Chile.

Correspondence: Fernando Vargas Gallardo. Bernardo OHiggins Av, Santiago 4848, Chile. **Email:** drfvargas@gmail.com. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** November 17, 2023. **Date accepted:** May 14, 2024. **Online:** August 30, 2024.

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computed tomography (CT) scans (Impax PACS, AGFA HEALTHCARE, Mortsel, Belgium).

All patients were operated on with open reduction and internal fixation. A dorsolateral approach was used centered on the cuboid, and as required, it extended proximally to the tip of the fibula and distal to the fourth metatarsal base. Three different types of osteosynthesis were used according to fracture pattern: screws, locking plates, or bridging plates.

After surgery, the patient was instructed to use a cam walker boot, non-weight bearing, range of motion exercises, and foot raise. Sutures were removed after three weeks to start rehabilitation.

Results

Twenty-seven patients (19 men, eight women) with a mean age of 41.3 years (range: 23-62 years) with a diagnosis of displaced cuboid fracture were admitted and operated on. Most patients (25/27, 92.5%) were working compensation (Table 1).

In our series, two patterns or types of fracture related to articular involvement of calcaneocuboid joint or cuboid-metatarsal joint: fracture with involvement of one articular surface (13 patients), fracture with involvement of two articular surfaces (14 patients) were identified. There were no cases without articular compromise. Lateral column shortening was observed in 12 patients (44.4%). Twenty-two patients (81.5%) had associated midfoot injuries. The most frequent injuries were navicular fracture (11 patients), Lisfranc injury (10 patients), and six with cuneiform fracture (Figure 1).

Regarding the mechanisms of injury, the most frequent were motor vehicle accidents, falls from height, and crushing. Three cases required bone grafts due to severe bone loss and articular surface without a reconstruction option.

The mean radiological follow-up was 3.3 years (0.3 to 10.5). Fracture healing was observed in 100% of patients. Regarding the type of osteosynthesis used, 20 patients used locking plates: 15 used an anatomical cuboid 2.4 locking plate, and five used a locking 2.4/2.7 mm T plate. Three patients required a bridging plate and bone graft due to several comminution of the cuboid and articular surfaces. Four patients used only 2.7 screws. One patient required a temporary external fixator due to soft tissue involvement.

The type of osteosynthesis used was related to the fracture pattern observed. Due to this observation, a simple treatment algorithm was used for cuboid fracture management:

- **Type 1**: **Simple Fracture:** this is a fracture without comminution.
- **Type 2: Comminuted Fracture**: was divided into three types:
  - **Type 2A: Central comminution;**
  - **Type 2B: Articular comminution;**
  - **Type 2C: Burst fractures**.

Additionally, type 2B was subclassified into two types regarding the possibility of performing a stable reduction and fixation of the articular surface or not:

- **Type 2B: Articular comminution:**
  - **Type 2B1**: synthesizable articular surface;
  - **Type 2B2:** not synthesizable articular surface.

Due to this, the specific type of osteosynthesis and the need for bone grafts were according to the classification shown. As an example, the following cases are shown.

Case 1. A 23-year-old woman's left foot was crushed by a car wheel, resulting in a cuboid fracture with no reconstructable distal cuboid articular surface and body comminution (Figure 2). It was classified as a type 2B2 fracture. Resection of the bone and cartilage comminution were performed at the time of surgery, then an iliac crest structural autograft with preservation of periosteum was applied as cuboid-metatarsal joint surface reconstruction (Figure 3), and fixation performed with an anatomic cuboid locking plate (Figures 4 and 5).

Case 2. A 49-year-old woman suffers a forced inversion of her left foot. The CT scan (Figure 6) showed a cuboid fracture involving the calcaneal articular surface (Fracture Type 2B1). In the lateral approach to the cuboid, the articular

Table 1. Distribution of patients according to sex, injury mechanism, and fracture type

Variable	Value
Age (median)	41.3 y (range 23 - 62)
Sex	
Male	19
Female	8
Injury Type	
MVA	6
Fall from height	6
Crush	7
Sprain	8
Fracture pattern	
Partial articular involvement	14
Biarticular involvement	13

MVA: Motor vehicle accident.

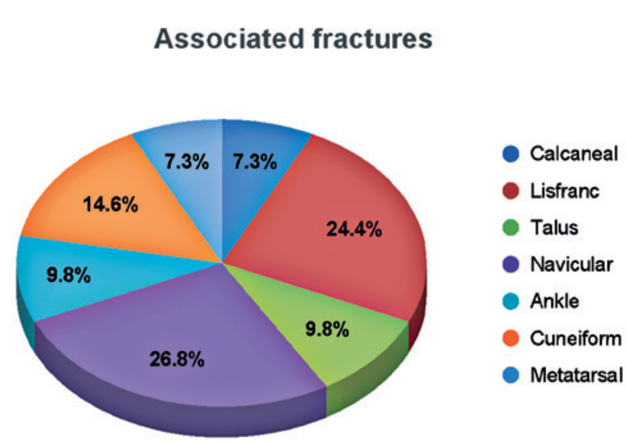

Figure 1. Associated fractures.

fragments were reduced temporarily with 1.6 Kirschner wires. The reduction was verified by direct vision using fluoroscopy. Once proper reduction was achieved, the fixation was performed with a locking cuboid plate. Postoperative control with a CT scan showed a satisfactory joint facet reduction (Figure 7).

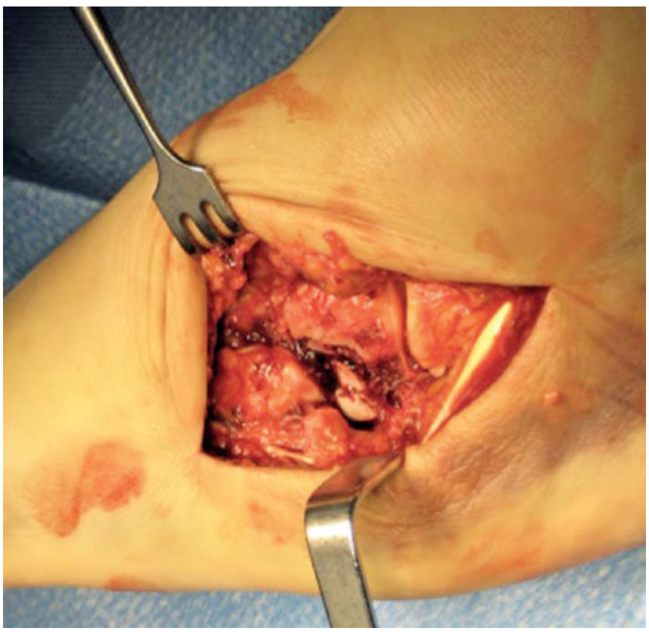

Figure 2. Cuboid fracture with no reduction distal cuboid articular facet.

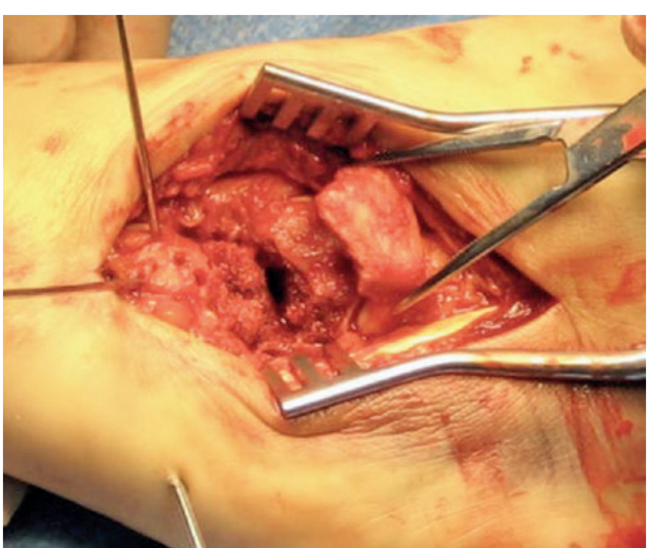

Figure 3. Iliac crest structural autograft, with preservation of periosteum, applied as cuboid-metatarsal joint surface reconstruction.

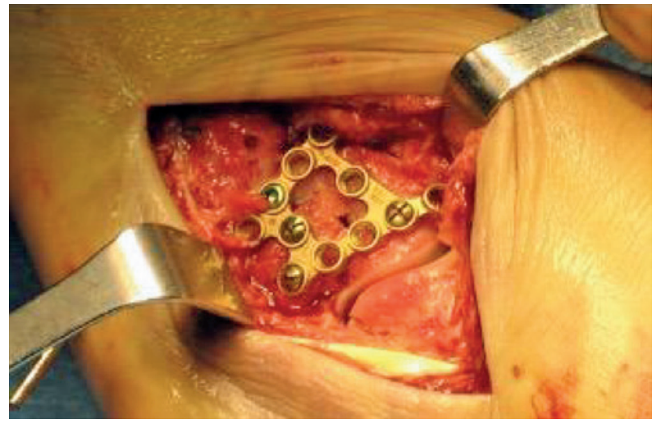

Figure 4. Cuboid fixation performed with an anatomic cuboid locking plate.

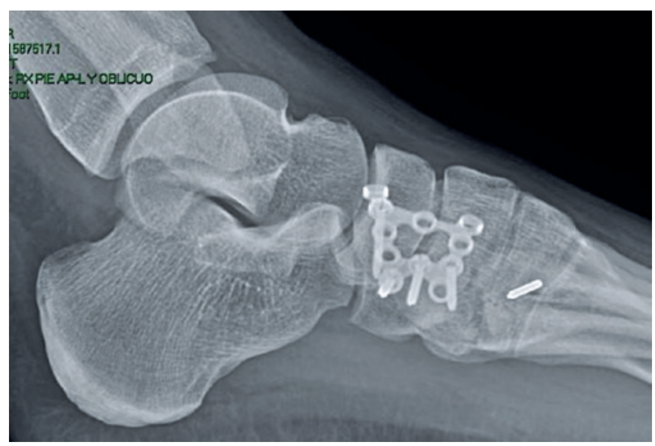

Figure 5. Postoperative radiograph showing reduced cuboid fracture.

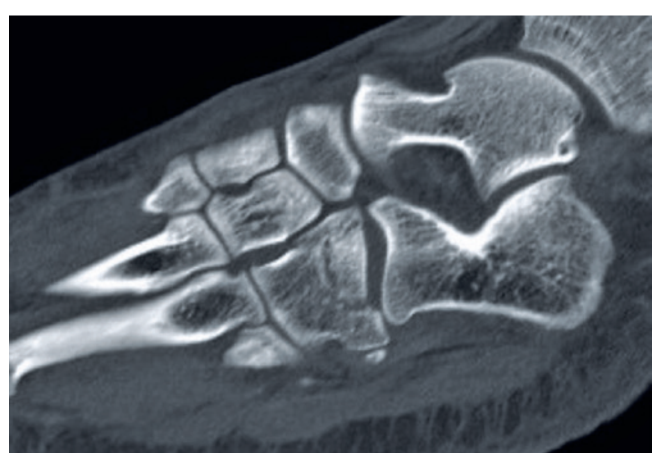

Figure 6. Preoperative CT scan: cuboid fracture involving the calcaneal articular surface.

Figure 7. Postoperative CT scan with articular reduction.

At 3.3 years of follow-up, 81.5% of the patients showed signs of arthritis on radiographs, such as narrowing articular space, osteophytes, and geodes, among others. These signs were more frequent in those patients presenting with cuboid-metatarsal joint involvement (94.4%) vs. those the fracture compromised the joint facet with the calcaneus (55%).

One case of superficial wound infection required serial dressing changes and oral antibiotics. Another patient required plastic surgery coverage due to a poor soft tissue envelope caused by the initial injury (truck crash).

The treatment algorithm schematized in Table 2 is presented to standardize the management of the cuboid fracture. The type of osteosynthesis was suggested according to the type of fracture and joint involvement. The suggestion included the use of isolated screws for simple fractures, locking plates for more comminuted fractures, and bridging plates or external fixation for those high-energy burst fractures with articular destruction. For cases with articular involvement, the feasibility of reduction and osteosynthesis of the articular surface must be evaluated. If possible, a locking plate and central structural graft are suggested to support the reduction. If it was not possible to reduce the facet, it was proposed that an iliac crest graft with periosteum be used to replace the compromised joint surface. It is believed that it is a simple and reproducible algorithm, understanding that there may be cases where it is necessary to perform other procedures to achieve an adequate result.

Discussion

The cuboid fracture is an uncommon injury. In a retrospective series of 155 patients with midfoot fractures, Richter et al.[12] found 58 cuboid fractures. Shibuya et al.[13], in an epidemiological analysis of more than 280,000 foot and ankle fractures, report a 2.7% (n = 7,659) incidence of cuboid fracture.

Classically, two mechanisms of injury have been described: compression or “Nutcracker” and distractive or avulsive[14,15]. Also, isolated cuboid fractures have been reported in the literature[2-5]. Sangeorzan[2] in 1990 reported four cases of cuboid fracture treated surgically. In 2001, Miller[3] described the case of a patient treated non-surgically, and Van Raaij et al.[5] published their findings on four patients treated with internal fixation.

Usually, the nutcracker fracture would be more related to high-energy injuries[15,16]. Hermel and Gershon-Cohen described this fracture as caused by cuboid compression between the bases of the fourth and fifth metatarsals and the calcaneus due to plantar-flexion forces[15]. In our series, 27 patients had this type of fracture. No avulsion fractures were found in our sample. All patients had joint involvement of one or both articular surfaces. This could be because, in our study, 70.3% of the patients (19 of 27) presented high-energy mechanisms: falls from height, motor vehicle accidents, or crushing. In the literature, there are few reports of nutcracker fractures. Yu et al.[11] showed the results of a series of six patients with this type of fracture, while in another series, Weber and Locher[10] published their results in 12 patients with a mean follow-up of 27 months. In 10 years, Holbein[9] treated four patients with this type of fracture. Fenton et al.[17] described 12 patients with nutcracker fractures, of which three were submitted to cuboid open reduction and internal fixation and two with an external fixator.

The most frequent is that the cuboid fracture is accompanied by other foot injuries[6,14-16,18,19]. Hermel and Gershon-Cohen[14], in 1953, published five cases of nutcracker-type cuboid fractures, describing four associated injuries. Ten of the 12 patients in the series published by Martin Weber[10] had associated injuries. Our results are in line with the literature. Twenty-four of the 27 patients (88.9 %) presented associated midfoot injuries; the most frequent were navicular, Lisfranc, and cuneiform fractures. As previously noted, these findings are likely related to the high-energy mechanism in our series. Given this frequent association, a complete image study with AP, lateral and oblique radiographs, and a CT scan of the affected foot are indispensable in patient evaluation, along with a detailed physical examination.

Table 2. Management algorithm

Type 1 Simple fracture (non comminution)	**Type 2** Comminuted			
	Type 2A Central comminution	**Type 2B** Articular comminution		**Type 2C** Burst fractures
		Type 2B1 synthesizable articular surface	**Type 2b2** non synthesizable articular surface	
Without bone graft RAFI with screws	Central bone graft RAFI w/locking plate	Reduction articular surface Structural graft RAFI w/locking plate	Resection articular small pieces Iliac crest bone graft w/periosteum RAFI w/locking plate	Iliac crest bone graft w/periosteum External fixation or bridging plate

The cuboid fracture can compromise the integrity of the lateral column, composed of the calcaneus and fourth and fifth metatarsals[15,16]. The lateral column is the moving column of the foot[20,21]. It allows, among others, mechanical properties to improve stability in irregular surfaces and the absorption of energy in the stance phase of the gait cycle[15,20]. The cuboid fracture may lead to a lateral column shortening, which could generate a secondary flat foot[6,15]. It is, therefore, necessary to manage this injury to correct this shortening and restore the articular surface of the cuboid. For injuries without displacement, in general, the literature supports the conservative treatment[8]. Furthermore, different methods for managing displaced or articular compromise injuries have been described, and there is no clear consensus in the literature[2,5,6,9-11,17]. Sangeorzan[2] recommended the reduction and internal osteosynthesis for the injuries displaced or with comminution. In his report, Sangeorzan showed four cases and used different osteosynthesis according to the specific case: Kirschner wires, screws alone, or plates. In the series of 12 patients published by Weber[10], in eight patients, one or two plates were used, and in four just screws as a method of fixation. In our study, most patients required a plate for osteosynthesis: 20 of 27. A bridging plate was needed in three cases. As noted, 100% of our cases presented a compromise of one or both joint facets, usually with some degree of comminution. We believe that using a locking plate allows a fixation in the fracture reconstruction of the cuboid, obtaining the stability of the construct, which could improve consolidation and recovery of this area. This stability would allow for earlier rehabilitation than using a less stable fixation.

The use of bone grafts and which one to use are controversial topics in the literature. In seven of 12 cases presented by Martin Weber[10], an iliac crest graft was used to improve the bone support. Sangeorzan[2] used grafts in three of the four patients. In a more recent study, Yu et al.[11] used allograft without specifying how many patients required it. Holbein[9], in two of the four cases, required an iliac crest graft. In our series, three patients required an iliac crest graft. In the three cases, the cortical aspect of the graft replaced the articular surface of the cuboid, given the irreparable damage it presented. The replacement allowed a sort of “rebuilding” of this joint, thereby maintaining the length of the lateral column and avoiding the acute arthrodesis of the cuboid-metatarsal joint.

Osteoarthritis is another complication associated with this type of injury when the articular surfaces are compromised [5,6,15,16,22,23]. Howie[22] reported that four of five patients presented symptomatic osteoarthritis of the calcaneocuboid joint. On the other hand, Van Raaij[5], in a mean follow-up of 2.8 years, reported three patients with arthritis signs that did not require surgical management. In the Weber[10] series, with a mean follow-up of 27 months for the four patients with calcaneocuboid joint compromised, one presented signs of osteoarthritis. On the other hand, the same author points out that of the 11 patients with tarsometatarsal involvement, two presented symptomatology; they say that a longer follow-up was necessary. In our series, some differences were found compared with the literature. At 3.3 years follow-up, 81.5% of the patients showed signs of osteoarthritis on the control radiograph. These signs were more frequent in patients presenting cubo-metatarsal joint involvement vs those in which the fracture compromised the joint facet with the calcaneus (94.4% vs. 55%, respectively). A possible explanation for this finding is that they presented joint involvement with varying degrees of comminution in all cases. In addition, the joint articular surface was replaced in three cases with periostic iliac crest autograft. The involvement of this joint and the greater mobility of the lateral column could explain the progression of arthritic changes in these joints.

Our study has limitations, such as the retrospective case series design and the midterm follow-up, which should be complemented with a longer follow-up period to establish more definitive results.

Conclusion

Cuboid fracture is an infrequent injury and should be considered a complex injury given its importance in the conformation of the lateral column of the foot and its implications in the biomechanics of the gait cycle. There is an important association with other injuries, which it must rule out with the physical examination and the image analysis of both radiographs and CT scans. We present a management algorithm for this injury based on a long series of cuboid fractures, which we believe are simple to reproduce.

Authors' contributions: Each author contributed individually and significantly to the development of this article: FVG *(https://orcid.org/0000-0002-4283-2900) Conceived and planned the activity that led to the study, wrote the article, participated in the review process; LLS *(https://orcid.org/0000-0002-7010-7490) data collection, bibliographic review; MPH *(https://orcid.org/0000-0002-0859-6975) formatting of the article, bibliographic review; CUB *(https://orcid.org/0000-0002-2328-2835)interpreted the results of the study, participated in the review process; JBG *(https://orcid.org/0000-0001-9018-7021), and CBS *(https://orcid.org/0000-0001-8049-5098) Performed the surgeries; data collection, statistical analysis. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Original Article

Comparative clinical and radiographic results of three fixation systems for transverse subcapital osteotomy in treating hallux valgus

Ezequiel Catá[1], Ignacio Hernan Nieto[1]

1. Sanatorio Allende, Córdoba, Argentina.

Abstract

Objective: Compare three fixation models for Bosch osteotomy both clinically and radiographically.

Methods: A retrospective comparative study was conducted on patients surgically treated for hallux valgus using Bosch osteotomy with three different fixation systems. The first group was treated with a temporary pin for three weeks; the second, received the same pin plus a screw; and the third, used two screws without a pin. Radiographic analysis included the intermetatarsal angle, metatarsophalangeal angle, percentage of lateral shifting of the metatarsal head, dorsal or plantar migration of the metatarsal head, and consolidation time. Clinical evaluation was performed using the American Orthopaedic Foot and Ankle Society (AOFAS) scale. Complications during follow-up were recorded.

Results: Twenty hallux valgus were included in each group. No significant differences were found in radiographic evaluations among groups in the preoperative and final follow-up, except that the third group showed less loss of correction. There were no significant differences in consolidation times. Clinical improvements were observed in all three fixation systems, with no significant differences among them according to the AOFAS scale.

Conclusion: No significant clinical or radiographic differences were observed among the three fixation systems, except that the group using two screws showed less loss of correction.

Level of evidence IV; Therapeutic studies; Case series.

Keywords: Hallux valgus, osteotomy, minimally invasive.

Introduction

Even though more than 130 surgical techniques to treat hallux valgus have been described, there is as yet no consensus on which of these is the most effective. Minimally invasive surgery has gained increasing interest and acceptance in recent decades due to several advantages, including achieving strong corrections, rapid recovery, better cosmetic appearance, a low complication rate, and cost-effectiveness[1,2]. In 1990, Bosch et al. introduced the minimally invasive transverse subcapital osteotomy with temporary fixation using a single Kirschner pin[3]. This technique served as the foundation for subsequent minimally invasive distal techniques, which involved the lateral shifting of the first metatarsal head. While numerous studies have demonstrated favorable clinical and radiographic outcomes using the Bosch osteotomy, some authors have raised concerns regarding the stability provided by the Kirschner pin as the sole fixation system[3-11]. To enhance stability and create a more mechanically robust system, the simple transverse osteotomy has been modified to a chevron-type osteotomy. This modification is primarily in the shape of the osteotomy rather than the fixation method, although the chevron-type osteotomy often includes the addition of one or two screws

Study performed at the Sanatorio Allende, Córdoba, Argentina.

Correspondence: Ezequiel Catá. Independecia 757. CP: 5000, Nueva Córdoba, Córdoba, Argentina. **Email:** ezecata@gmail.com. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** February 02, 2024. **Date accepted**: July 30, 2024. **Online:** August 30, 2024.

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for improved stability[12]. The concern with this modification is the extent to which the chevron-type osteotomy can provide stability to the plantar limb during extensive lateral shifting, given the minimal bone contact. Although studies have been published comparing different percutaneous techniques, and these with conventional procedures, we have not found studies that assess different fixation methods for Bosch osteotomy[13-20].

The objective of our study is to clinically and radiographically compare and assess three groups of patients diagnosed with hallux valgus who underwent Bosch osteotomy using three different fixation systems, with a minimum follow-up of one year. First group was treated with a temporary pin for three weeks, second group received the same pin plus a screw, and third group was treated with two screws without a pin.

Our hypothesis is that there is no significant differences between the three groups by the end of the minimum one-year follow-up period.

Methods

A retrospective cohort study was designed, which was longitudinal, observational, and with deliberate but not controlled interventions. Sixty hallux valgus cases surgically treated with Bosch osteotomy were included. These were divided into three groups according to the fixation system used: Group 1 (G1) – Bosch osteotomy plus a temporary pin for three weeks plus adductor tenotomy; Group 2 (G2) – Bosch osteotomy plus a temporary pin for three weeks plus a screw with adductor tenotomy; and Group 3 (G3) – Bosch osteotomy plus two screws with no pin plus adductor tenotomy (Figure 1). The sample size of 60 patients was determined based on clinical feasibility and prior similar studies assessing surgical outcomes in hallux valgus surgery.

Inclusion criteria were (1) patients older than 18 years with painful hallux valgus; (2) failure of a more than two-month-long conservative treatment, including oral medications, shoe modification, and physical therapy; (3) mild, moderate, or severe hallux valgus according to the Coughlin classification; and (4) patients operated with Bosch osteotomy[21].

Exclusion criteria were (1) prior hallux valgus surgery; (2) first metatarsophalangeal joint arthritis; (3) additional forefoot procedures; (4) patients with any systemic disease affecting the musculoskeletal system (e.g. gout, systemic lupus erythematosus, rheumatoid arthritis); and (5) incomplete clinical or radiographic follow-up of less than one year.

All patients were followed up for at least one year. Groups 1 and 2, being the initial techniques implemented, were followed up for an extended period of two years. Group 3, representing the newer approach, also had a follow-up period exceeding one year.

Patients were functionally assessed using the scale from the American Orthopaedic Foot and Ankle Society (AOFAS)[22].

Weight-bearing digital X-rays were obtained in the anteroposterior and lateral projections. They were taken preoperatively and immediately postoperatively, at 6 weeks, 12 weeks, and at the end of follow-up. The intermetatarsal angle (IMA) was measured between the longitudinal axis and first and second metatarsal, while the metatarsophalangeal angle (MTPA) was assessed between the longitudinal axes of the first metatarsal and first phalanx. The lateral shifting percentage of the first metatarsal head (LSP-1M) was assessed to determine the correction maintenance, defined as the lateral shifting distance divided by the total width of the metatarsal in weight-bearing anteroposterior X-rays taken at six weeks and at the end of follow-up (Figure 2)[23,24]. Dorsal and plantar migration were studied in millimeters of the metatarsal head

Figure 1. Group 1: Bosch osteotomy plus one temporary pin (A); Group 2: Bosch osteotomy plus one temporary pin and one screw (B); Group 3: Bosch osteotomy plus two screws (C).

(Mgr-DP) with weight-bearing lateral X-rays at six weeks and at the end of follow-up. Dorsal migrations were recorded using negative values and plantar migrations, using positive values (Figure 3). Consolidation time was studied, occurring when a bony bridge was observed in all four cortical regions in obtained projections[25]. Complications were recorded until the end of follow-up. All clinical and radiographic assessments were made by the author.

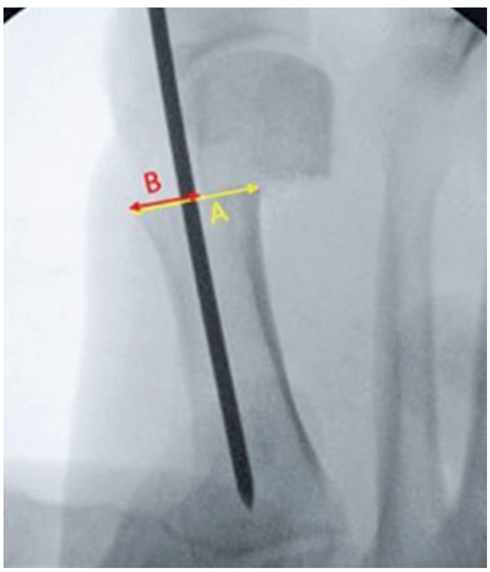

Figure 2. Lateral shifting percentage of the metatarsal head. Lateral shifting distance (B) divided by total width of the metatarsal (A).

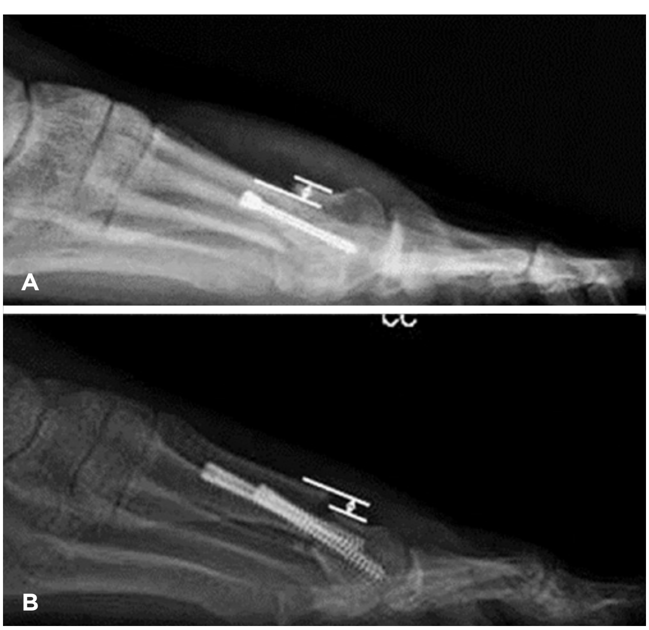

Figure 3. Dorsal-plantar migration of the metatarsal (in mm). Dorsal migrations recorded with negative values (A) and plantar migrations, with positive values (B).

Surgical Technique

All patients were operated on in the supine position, under regional anesthesia guided by ultrasound. A 5 cm Esmarch bandage was used on the ankle as a tourniquet. The adductor tendon was released after osteotomy in all patients. Procedures were guided by an image intensifier.

Group 1: Bosch osteotomy

The Bosch osteotomy[7] begins with a 2 mm medial incision in the nail fold. A 2 mm Kirschner pin is introduced superficial to the periosteum from the distal end of the hallux, backwards up to the distal metaphysis of the first metatarsal. A 1-cm-long skin incision follows at the neck level. Dissection by planes is carried out carefully to avoid damaging nerves. A small periosteum elevator is used to unstick it both at the dorsal and plantar levels to create a safe working area. A 1.4 mm Kirschner pin is placed as a cutting guide perpendicular to the diaphysis of the first metatarsal. Osteotomy is made with a 5 mm x 15 mm x 0.4 mm cutting saw; the cutting guide pin is removed and the head is laterally shifted with the aid of a grooved probe. The intramedullary Kirschner pin is advanced for fixation in the base of the first metatarsal (Figure 4). Wounds are closed and bandaged using compressive self-adhesive bandages.

Group 2: Bosch osteotomy plus one screw

Same as the procedure for G1. Once the Kirschner pin has been placed, a 2 cm proximal and medial osteotomy incision is made and a 1.0 mm guide pin is placed obliquely directed towards the first metatarsal head, without interrupting the joint surface. The guide pin is then measured and drilled to ensure proper placement. Following this, a 3.0 mm double-thread, cannulated screw is placed (Figure 5). Wounds are closed and bandaged using compressive self-adhesive bandages.

Group 3: Bosch osteotomy plus two screws with no pin

Same as the procedure for G1. Once the Kirschner pin has been placed, two proximal and medial osteotomy incisions are made at 2 cm and 5 cm; two 1.0 mm parallel guide pins are placed obliquely directed towards the first metatarsal head. The guide pin is then measured and drilled to ensure proper placement. Following this, two 4.0 mm double-thread, cannulated screws are placed, first the proximal one, then the distal one. The 2 mm Kirschner pin is removed (Figure 6). Wounds are closed and bandaged using compressive self-adhesive bandages.

Patients began immediate weight-bearing with the use of stiff-soled postoperative footwear. Bandages were changed on the first week and on the third week. In G1 and G2, Kirschner pins were removed on the third week.

Statistical Analysis

With respect to the descriptive statistics, the absolute and relative frequencies of qualitative variables were calculated,

Figure 4. Bosch osteotomy plus temporary pin (Group 1), 24-month follow-up.

and double-entry tables were drawn up, calculated per column. The mean, median, and standard deviation of quantitative variables were also estimated. For statistical inference, Pearson's chi-squared test was used, when possible, to study the relationship among qualitative variables; when its use was not possible, Fisher's exact statistic was calculated in the 2x2 tables. To analyze the difference between quantitative variables, the usual Student's t-test was used for independent samples, related samples and for the analysis of variance (ANOVA). For statistical analyses, SPSS for Windows v. 22 was used, and the level of significance in all cases was the usual, 0.05.

Results

A total of 60 hallux valgus in a total of 55 patients were included (5 bilateral). Each group was made up of 20 feet. Demographic data of groups can be seen in table 1.

The mean follow-up time was 60 months (SD: 8.1), 34.4 months (SD: 8.7), and 13.7 months (SD: 20.5) for G1, G2, and G3, respectively, with a statistically significant difference ($p < 0.05$).

Angular radiographic values showed significant modifications in each group and when comparing the preoperative and the end of follow-up values (Table 2). For G1, changes were: preop IMA: 13.5° (SD: 5.6), postop IMA: 8.0° (SD: 2.4), $p < 0.0003$; preop MTPA: 25.8° (SD: 8.6), postop MTPA: 9.1°

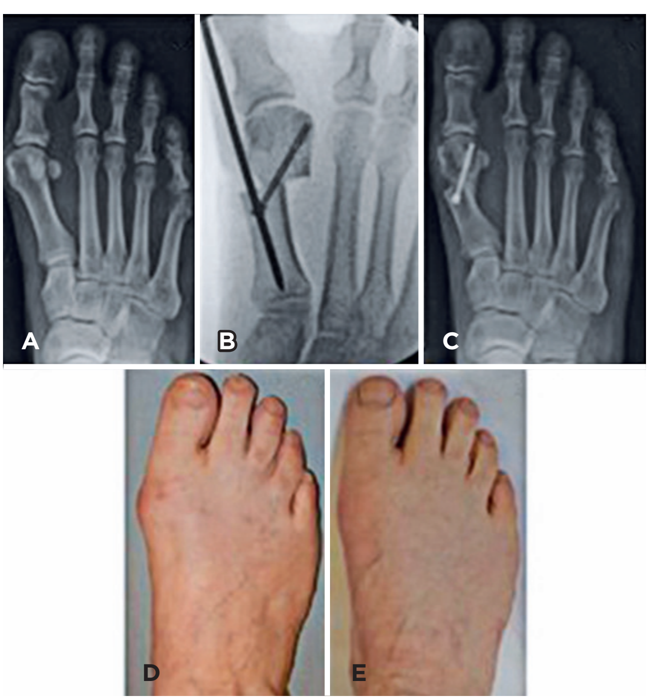

Figure 5. Bosch osteotomy plus temporary pin (Group 2), 18-month follow-up.

Figure 6. Bosch osteotomy plus two screws (Group 3), 12-month follow-up.

Table 1. Demographic data

	G1	G2	G3	p
Age, mean	54,6 ± 13,2	52,6 ± 14,9	53,9 ± 12,7	0.90
Sex, female/male	18/2	19/1	17/3	0.52
Side, right/left	10/10	10/10	11/9	0.06

G1: Bosch osteotomy plus one pin; G2: Bosch osteotomy plus one screw; G3: Bosch osteotomy plus two screws.

Table 2. Clinical and radiographic results

	G1	G2	G3	p
Preop AOFAS				
Scale	54.8	53.3	52.3	0.72
Postop	98.2	98.4	98.2	0.92
p	0.001	0.001	0.001	
Preop				
IMA	13.5	13.2	13.6	0.95
Postop	8.0	7.7	6.7	0.18
p	0.003	0.002	0.001	
Preop				
MTPA	25.8	26.1	25.2	0.95
Postop	9.1	9.2	7.1	0.24
p	0.001	0.001	0.001	
LSP-1M				
sixth week	54.7	55.6	57.7	0.85
Postop	47.7	47.8	56.0	0.04
p	0.009	0.002	0.13	
Mgr-DP				
sixth week	0.7	0.5	0.2	0.43
Postop	0.5	0.7	0.3	0.22
p	0.129	0.16	0.21	

G1: Bosch osteotomy plus one pin; G2: Bosch osteotomy plus one screw; G3: Bosch osteotomy plus two screws; IMA: intermetatarsal angle; MTPA: metatarsophalangeal angle; LSP-1M: percentage of lateral shifting; Mgr-DP: dorsal or plantar migration.

(SD: 5.0), p < 0.0001. For G2, differences were: preop IMA: 13.2° (SD: 4.1), postop IMA: 7.7° (SD: 2.5), p < 0.0001; preop MTPA: 26.1° (SD: 9.9), postop MTPA: 9.2° (SD: 3.8), p < 0.0001. For G3, changes were: preop IMA 13.6° (SD: 4.5), postop IMA: 6.7° (SD: 1.9), p < 0.0001; preop MTPA: 25.2° (SD: 9.7), postop MTPA: 7.1° (SD: 4.4), p < 0.0001.

Analyzing the LSP-1M, we detect a loss of correction maintenance, with a significant difference between the sixth week and end of follow-up for G1 and G2, but not for G3. In G1, changes were: sixth week: 54.7% (SD: 10.7), postop: 47.0% (SD: 15.2), p < 0.0009; for G2, sixth week: 55.6% (SD: 16.7), postop: 47.8% (SD: 16.4), p < 0.0028; and for G3, sixth week: 57.7% (SD: 22.3), postop: 56.0% (SD: 23.4), p > 0.13.

With respect to dorsal and plantar migration, there were no significant differences between the sixth week and the end of follow-up in each group. For G1, changes were: sixth week: 0.7 mm (SD: 0.9), postop: 0.5 mm (SD: 0.9), p > 0.12; for G2, sixth week: 0.5 mm (SD: 1.1), postop: 0.7 mm (SD: 1.1), p > 0.16; and for G3, sixth week: 0.2 mm (SD: 1.0), postop: 0.3 mm (SD: 0.9), p > 0.21.

Clinical results (AOFAS scale) showed significant differences in each group between the preoperative and postoperative periods. In G1, changes were: preop: 54.75 (SD: 10.8), postop: 98.8 (SD: 2.4), p < 0.00001; in G2, preop: 53.1 (SD: 9.0), postop: 98.4 (SD: 1.2), p < 0.00001; and in G3, preop: 52.3 (SD: 7.6), postop: 98.2 (SD: 1.7), p < 0.00001. Comparing the radiographic results among the three groups, we did not detect any significant changes in preoperative (IMA: p > 0.95, MTPA: p > 0.95, Mgr-DP: p > 0.43, LSP-1M: p < 0.85) or end of follow-up (IMA: p > 0.18, MTPA: p > 0.24, Mgr-DP: p > 0.22) findings, which did not apply to LSP-1M (p < 0.04). Furthermore, we did not find any significant differences among groups in clinical evaluation (AOFAS scale) in the preoperative (p > 0.72) and end of follow-up periods (p > 0.92).

The mean consolidation time was 12.9 weeks, 12.3 weeks, and 12.5 weeks for G1, G2, and G3, respectively, without any significant changes among groups (p > 0.637).

Total percentage of complications was 16.7%. In G1, the complication rate was 20%, including two superficial infections at the Kirschner pin entry point, which required early removal and oral antibiotic therapy. One patient experienced a 4-month delay in consolidation that did not require surgery. Another patient had a loss of correction and recurrence of hallux valgus and did not agree to reoperation. In G2, the complication rate was 15%, including one superficial infection of the surgical wound, managed with local healing and oral antibiotics. One patient had a consolidation delay that resolved over 5 months. Another patient had a loose screw that required removal. Additionally, two patients were intolerant to the osteosynthesis material, presenting with skin irritation, and were reoperated to remove the material. In G3, the complication rate was 15%, with one intraoperative fracture of the metatarsal diaphysis while placing the distal screw. It was decided to retain the osteosynthesis and delay weight-bearing for three weeks; consolidation of the osteotomy was observed nine weeks post-surgery. One patient experienced a loosening of one of the screws, removal required, and another patient required screw removal due to prominence and discomfort with footwear. While complication rates for G1, G2, and G3 were 20%, 15%, and 15%, respectively, it is important to note that, due to the small sample size, statistical comparisons among groups are not feasible. Further studies with larger sample sizes are needed to draw definitive conclusions.

Discussion

In current literature, comparative studies on different fixation systems for Bosch osteotomy are lacking. Our study provides a clinical and radiographic analysis with a minimum follow-up of one year, evaluating three fixation systems for this osteotomy. All three systems demonstrated favorable clinical and functional outcomes. No significant differences were found among groups in clinical results or in most radiographic parameters. However, a notable difference was observed in the maintenance of lateral shifting correction, with G3 showing a lower loss of correction.

Since the advent of minimally invasive surgery for the treatment of hallux valgus, techniques have evolved from osteotomy with no fixation (first generation), through transverse osteotomy plus fixation with Kirschner pins (second generation), to chevron-type osteotomy plus fixation with one or two screws (third generation). Although Bosch osteotomy has shown good clinical and radiographic results, some authors criticize the lack of mechanical stability provided by the pin, skin complications related to the procedure, a lack of early mobility, and loss of correction[10,12]. Based on the rationale of lateral shifting, Vernois and Redfern modified transverse osteotomy to a chevron-type osteotomy with two screws, abandoning the use of pins[26]. Although this modification offers inherent advantages for structural stability with the plantar limb, it does not allow for improved control of rotation (pronation), a benefit provided by Bosch osteotomy. The incorporation of two screws in Bosch osteotomy, inspired by the chevron-type osteotomy, has not been extensively studied, highlighting a gap in the literature. Our study observed that the use of two screws in Bosch osteotomy (G3) provided robust fixation, enhancing stability and maintaining the correction. Additionally, our clinical and radiographic results showed no mechanical failures with Bosch osteotomy, confirming its reliability. Aiyer et al. published a study on cadavers comparing failures and stability between Bosch osteotomy and chevron-type osteotomy fixed with two screws in nine pairs of hallux, finding no significant differences in biomechanical stability between these methods, supporting our observations[27].

Few publications exist on Bosch osteotomies with a single screw as the fixation system. In 2020, Carlucci et al. published a retrospective comparative study on Bosch osteotomy with one screw vs. minimally invasive chevron-type osteotomy with two screws. Their results showed similar clinical and radiographic outcomes for both groups with one year follow-up, aligning with the findings for G2 in our study[19]. Yañez Arauz et al. further investigated these techniques in a radiographic prospective study, noting that Bosch osteotomy provided a greater medium-term correction of the IMA, while the chevron-type osteotomy showed better correction and maintenance of the distal joint angle of the metatarsal. However, they did not clarify whether these differences had clinical significance for patients[28].

With respect to complications in general, we report a rate of 16.7%. Though this is similar to reports from other studies, no conclusive comparisons can be made among the three groups due to the small sample size.

While the results of our work are similar among the three fixation systems, cautious is needed in their interpretation due to the limitations of a retrospective study, including a small sample size and the short follow-up period.

Conclusion

All three systems showed favorable clinical and functional outcomes, with no significant differences in clinical results or in most radiographic parameters. However, a statistically significant difference was observed in the maintenance of lateral shifting correction, with the G3 system demonstrating a lower loss of correction compared to the others. While the G3 system requires a longer learning curve, its superior performance in maintaining correction justifies its continued use in clinical practice. Further research is needed to explore long-term outcomes and validate these findings over extended periods.

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Original Article

Effectiveness of neurokinetic therapy on pain and plantar fascia thickness among patients with plantar fasciitis

Preethi Shri Prajan[1], Kumaresan Abathsagayam[1], Surya Vishnuram[1]

1. BPT, Saveetha College of Physiotherapy, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamilnadu, India.

Abstract

Objectives: Identify the effectiveness of neurokinetic therapy on pain and plantar fascia thickness in patients with plantar fasciitis.

Methods: An experimental study was performed on 80 patients with plantar fasciitis after screening based on selection criteria. The patients were randomly allocated into two groups: the neurokinetic therapy group (n = 40) and the foot core exercises group (n = 40). In both groups, the treatments were given for two weeks, five days each week. The pre-and post-test results were assessed. A statistical analysis was performed on the gathered data.

Result: A significant statistical difference was observed between the groups; the post-test mean value of the Foot Function Index scale in the neurokinetic therapy group was 129.12, while in the foot core exercises group was 141.42. Additionally, the post-test mean value of the therapeutic ultrasound in the neurokinetic therapy group was 3, whereas in the foot core exercises group was 3.38. These values yielded a p-value of less than 0.001.

Conclusion: This study demonstrated an improvement in both groups. However, the neurokinetic therapy group showed a significant improvement in pain, functionality, and plantar fascia thickness compared to the foot core exercises group.

Level of evidence IV; Experimental study.

Keywords: Plantar Fasciitis; Therapeutic ultrasound; Heel spur; Calcaneus; Fibromatosis; Plantar.

Introduction

Plantar fasciitis is also referred to as plantar fasciosis. This condition often triggers an inflammatory reaction brought on by the degradation of the plantar fascia(1). Even though the term "fasciitis" implies an inflammatory origin, the condition was believed to stem from the wear and tear on the plantar fascia. As a result, some prefer to use the term "plantar fasciopathy" to describe the condition(2). The lifetime incidence of plantar fasciitis stands at 10%, impacting individuals of all age groups. However, patients aged between 40 and 60 years old exhibited the highest prevalence, with a significant association between plantar fasciitis development and being overweight(1,3,4). During activities involving dynamic motions such as walking, running, and sprinting, midfoot motions were notably more extensive in women than men. Females often exhibit a greater strain rate in plantar aponeurosis than men, from when the heel makes contact until the entire body's center of mass reaches its lowest position vertically(5). The primary factors contributing to plantar fasciitis were mechanical overuse and age-related degenerative alterations in the plantar fascia(6). The initial symptom of plantar fasciitis was the discomfort or aching sensations upon initially standing and bearing weight after arising from sleep. The primary areas of pain were the heel and

Study performed at the Saveetha College of Physiotherapy, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamilnadu, India.

Correspondence: Kumaresan Abathsagayam. Saveetha College of Physiotherapy, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamilnadu, India. **Email:** kresh49@gmail.com. **Conflicts of interest**: none. **Source of funding:** none. **Date received:** April 6, 2024. **Date accepted:** May 21, 2024. **Online:** August 30, 2024.

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the underside of the foot. The pain was often described as a burning, dull, and throbbing sensation, which becomes more pronounced during walking, especially in uncomfortable flat shoes or when walking barefoot[2,7-9]. Plantar fasciitis could be confirmed when the plantar fascia thickness exceeds 4.0 mm (approximately 0.16 inches) in combination with reduced echogenicity or the fascia's margins become less distinct farther away from the calcaneus's anteroinferior edge[10]. The Windlass test was the sole specific objective examination to diagnose plantar fasciitis.

Foot core exercises were performed to maintain correct foot alignment, manage the arch's position, and trigger the proprioceptive receptors on the bottom of the foot to improve stability. Exercises such as toe spreads, foot doming, and towel curls, which had demonstrated their effectiveness in strengthening the muscles associated with the arch, might be considered potential strategies for improving stability[11]. Stretching is a training technique that intentionally elongates or extends a specific body part. It served a therapeutic purpose by alleviating cramps and enhancing day-to-day activities by promoting flexibility[12].

As described in David Weinstock's book, the Motor Control Center (MCC) was stimulated by muscle or functional deficiencies. Neurokinetic therapy (NKT) is a method that comprehends and applies motor control treatment to recognize movement patterns effectively[13]. Neurokinetic therapy was a manual muscle testing approach designed to activate the motor control center within the cerebellum, which was integral to the mind-body connection and the resolution of injuries, stress, and pain. It addressed the issue's root, effectively reprogramming dysfunctional movement patterns. The MCC within the cerebellum processes data, sending it to the limbic framework (fulfilling needs) and then to the cerebral cortex (making decisions). Subsequently, the information was relayed to the musculoskeletal system (executing actions)[14].

Therapeutic ultrasound (TUS) demonstrated notable improvements in foot function and increased active range of motion in ankle dorsiflexion, serving as key indicators of an effective therapy method that can expedite recovery among those experiencing plantar fasciitis[11]. Using TUS to measure plantar fascia thickening and record inflammatory results is a highly useful diagnostic technique[15].

The primary objective of this study is to identify the effectiveness of neurokinetic therapy on pain and plantar fascia thickness among patients with plantar fasciitis.

Methods

An experimental study was performed on patients diagnosed with plantar fasciitis who met the inclusion criteria, underwent a preliminary assessment involving Foot Functional Index (FFI) and TUS, and enlisted in the physiotherapy outpatient department at a city multi-specialty hospital. This study was conducted after the patients signed the informed consent form and the approval by the Institutional Review Board (IRB).

The study included 80 patients randomly divided into two groups using the concealed envelope method. The inclusion criteria consist of females aged 30 to 50 who exhibited a positive Windlass test, experienced medial plantar calcaneal discomfort, and reported pain during the initial steps after waking up. Patients submitted to recent physical treatment for plantar fasciitis, recent heel steroid injections or anti-inflammatory medication, had a history of calcaneal fracture, foot deformity, gait abnormalities, prior foot and ankle surgery, heart disease, paralysis, amyotrophic lateral sclerosis, and deep vein thrombosis were excluded from the study. Patients with systemic conditions affecting the feet, such as ankylosing spondylitis, rheumatoid arthritis, psoriatic arthritis, gout, and either type I or II diabetes, were also excluded from the study.

Neurokinetic therapy

Forty patients with plantar fasciitis were assigned neurokinetic therapy with TUS for 30 minutes per day. Neurokinetic therapy targeted the gastrocnemius and soleus muscles (calf muscles) for 25 minutes daily. The procedure involved testing the plantar flexors and dorsiflexors, stimulating the MCC if weakness was detected, and retesting until successful reprogramming. Gastrocnemius and soleus muscles were treated with resistance to plantar flexion in supine and prone lying positions.

Therapeutic ultrasound was administered following neurokinetic therapy with parameters set at a frequency rate of 1 MHz, an intensity level of 1.5 W/cm^2, applied for five minutes in continuous mode.

Foot core exercises

Another group of 40 patients with plantar fasciitis was assigned foot core exercises with TUS and stretching. Stretching of plantar fascia and calf muscles was performed for both legs, followed by foot core strengthening exercises and therapeutic ultrasound.

Outcome measures

Measures included the FFI questionnaire and TUS, assessing the impact of foot abnormalities on pain, functional constraints, and activity limitations and detecting changes in the plantar fascia thickness and ultrasound reflection.

Statistical analysis

Upon completing the data collection phase, the gathered information underwent tabulation and comprehensive analysis through various statistical methods. The Mann-Whitney Wilcoxon test was specifically used to examine closely and identify any significant changes between the distinct groups within the dataset. Concurrently, the paired t-test was employed to analyze and comprehend the significance of alterations occurring within each group.

Result

Demographic data

Demographic data was collected and assessed through descriptive and inferential statistical analyses.

The statistical values within the groups were examined using the Wilcoxon Signed Rank test. The median pre-and post-test values of FFI for the neurokinetic therapy group were 186.50 and 132.50, respectively. The value of Z statistic (based on positive ranks) was -5.512. The group showed a t-value of -820, with a p-value less than 0.001 (Table 1).

The mean pre-and post-test values of FFI for the foot core exercise group using paired t-test were 185.52 and 141.42, respectively. The FFI standard deviation of the pre-and post-test was 14.70 and 10.71, respectively. The mean difference was 44.10, while the standard deviation difference was 14.79. The t-value for the FFI was 18.84, and the p-value was < 0.001. The confidence interval for the mean difference, calculated with a 95% two-tailed significance level, ranged from 39.368 to 48.832 (Table 2).

Mean pre-and post-test values for the neurokinetic therapy group were 5.55 and 3.00, respectively. Standard deviations for pre-and post-test were 0.67 and 0.38. T-value was 26.51, and p-value was < 0.001. The 95% confidence interval for the mean difference ranged from 2.358 to 2.748.

Mean pre-and post-test values for the foot core exercise group were 5.76 and 3.38, respectively. Standard deviations for pre-and post-test were 0.65 and 0.39. T-value was 29.70, and the p-value was < 0.001. The 95% confidence interval for the mean difference ranged from 2.214 to 2.537 (Table 3).

Table 1. Pre-and post-test FFI values for the neurokinetic therapy group

Group		Median	t-test	z-value	p-value
Neurokinetic therapy group	Pre-test	186.50	-820	-5.512	< 0.001
	Post-test	132.50			

Table 2. Pre-and post-test FFI values for the foot core exercises group

Group		Mean ± SD	t-test	p-value
Foot core exercises group	Pre-test	185.52 ± 14.70	18.84	< 0.001
	Post-test	141.42 ± 10.71		

Table 3. Pre-and post-test TUS values for both groups

Group		Mean ± SD	t-test	p-value
Neurokinetic therapy group	Pre-test	5.55 ± 0.67	26.51	< 0.001
	Post-test	3.00 ± 0.38		
Foot core exercises group	Pre-test	5.76 ± 0.65	29.706	< 0.001
	Post-test	3.38 ± 0.39		

Post-Post-FFI was assessed using the Mann-Whitney Rank Sum test. Median values for FFI were 132.50 for the neurokinetic therapy group and 142 for the foot core exercise group. The Mann-Whitney U statistic was 467.500, and the t-value was 1287.500. The substantial median difference between groups was statistically significant (p = 0.001) (Table 4).

Using the equal variance test (Brown-Frorsythe), the mean difference was -0.386. Assuming equal variances (Student's t-test) resulted in a t-value of 4.435 with 78º of freedom. With equal variances not assumed (Welch's t-test), the t-value was -4.435 with 77.880º of freedom. The mean difference between groups was statistically significant (p < 0.001), indicating meaningful disparity (Table 5). The results suggest that the findings within and between groups were statistically significant, with a p-value < 0.001. Thus, neurokinetic therapy had significant effectiveness in improving pain relief, functionality, and plantar fascia thickness among patients with plantar fasciitis.

Discussion

This study was designed to identify effective therapeutic interventions, and it sought to evaluate the potential benefits of two distinct approaches: neurokinetic therapy and foot core exercises.

Fouda et al. performed a study incorporating radial shock wave therapy and TUS in addition to conventional physical therapy. They demonstrated notable efficacy in enhancing foot function and the active range of motion for ankle dorsiflexion in patients suffering from persistent plantar fasciitis. The TUS employed in the study had specific parameters, including a 1.5 W/cm^2 intensity at 1 MHz of frequency and five minutes of cm2 continuous application using longitudinal motions along the entire plantar fascia with a 5-transducer head. Notably, the same parameters applied in the study yielded significant improvements, reinforcing the positive outcomes[16].

The study by Nisha et al. demonstrated significant improvements in both pain and disability when employing neuro-

Table 4. Post-post-test FFI values for both groups

Post-post-test	Median	t-test	u-value	p-value
Neurokinetic therapy group	132.50	1287.500	467.50	< 0.001
Foot core exercises group	142			

Table 5. Comparison between the post-post-test TUS values for both groups

Post-post-test	Mean ± SD	t-test	p-value
Neurokinetic therapy group	3.00 ± 0.38	-4.435	< 0.001
Foot core exercises group	3.38 ± 0.39		

kinetic therapy compared to traditional exercises for cervical radiculopathy. The study highlighted several key effects, including muscle activity initiation and tissue viscoelasticity enhancement[14]. The study proposed that using dynamic myosin fiber activity alongside neurobiological training, guided by neurokinetic treatment principles, could improve the neuromuscular system in patients with plantar fasciitis. This approach may offer a more effective way to manage pain and dysfunction associated with the condition.

In their study, Yadav et al. demonstrated that self-stretching exercises and foam rolling designed for the plantar fascia contributed to alleviating pain and improving joint motion[17]. Zanon et al. showed the effectiveness of targeted stretching exercises for relieving chronic plantar fasciitis pain and improving performance. The results highlighted the efficacy of these stretching routines in significantly minimizing pain and enhancing performance abilities among patients with chronic plantar fasciitis[18].

Taddei et al. found that a foot core exercise program reduced the risk of running-related injuries in recreational runners after four to eight months of training[19]. Grecco et al. demonstrated shockwave therapy's effectiveness for plantar fasciitis, highlighting its physiological impacts on dense tissues like the plantar fascia and Achilles tendon. The study found that initial plantar fascia thickness ranged from 4.5 to 6.8 mm, indicating significant pain and functional limitations[20]. After neurokinetic therapy with TUS, there was a notable decrease in thickness associated with reduced pain and discomfort in plantar fasciitis.

Limitations of this study included its exclusive focus on women in the sub-acute phase and the inclusion of patients with bilateral plantar fasciitis. In the future, it's recommended to involve patients with persistent plantar fasciitis, investigate the integration potential of neurokinetic therapy with other treatments, and focus on particular occupational groups, maintaining consistent intervention strategies for plantar fasciitis.

Conclusion

The study compared the effectiveness of neurokinetic therapy and foot core exercises for treating plantar fasciitis. Both groups showed improvements in pain, functionality, and plantar fascia thickness. However, the neurokinetic therapy group, with therapeutic ultrasound, demonstrated greater reductions in pain, functional disability, and plantar fascia thickness compared to the foot core exercise group. Decreased plantar fascia thickness suggested potential therapeutic benefits for pain relief and improved functional outcomes in individuals with plantar fasciitis.

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Original Article

Single-stage management of Charcot neuroarthropathy and osteomyelitis in diabetic patients

Gonzalo Alvarez[1], Juan Pablo Randolino[1], Emanuel David Gonzalez[1], Laura Gaitan[1], Valeria Lopez[1]

1. Instituto Jaime Slullitel. Departamento de Cirugía de Pie y Tobillo, Rosario, Argentina.

Abstract

Objective: Describe our experience treating Charcot neuroarthropathy (CN) coexisting with concurrent bone infection in a single step, treated with external fixation, and report the mid-term radiographic and functional outcomes.

Methods: Retrospective case series of patients diagnosed with CN and osteomyelitis treated with a single-step approach consisting of necrotic bone debridement and fusion extended over the affected joints using a circular external fixator with a minimum of 18 months of follow-up.

Results: Six patients were evaluated, and three patients achieved excellent results and were able to walk outside their homes. One of them required a below-the-knee amputation due to persistent infection. Two patients had good results according to the Pinzur proposed evaluation scheme. All patients agreed that they would choose the reconstruction process for their deformity over an infrapatellar amputation.

Conclusion: We believe the results from our case series apply to the previously published literature on this therapeutic modality.

Level of evidence IV; Case series.

Keywords: Charcot; Diabetic foot; External fixation.

Introduction

Despite the long-standing recognition of osteomyelitis, its presence in the context of Charcot neuroarthropathy (CN) in the foot and ankle still poses a challenge regarding diagnosis, medical treatment, and reconstruction. The most significant risk factor for the concurrent occurrence of CN and osteomyelitis is a pre-existing ulceration in a patient with established neuropathy, which has been shown to increase the risk of limb loss dramatically. Furthermore, a severely dislocated and unstable foot or ankle due to CN also acts as a predisposing factor for the development of osteomyelitis, even though the most common cause of superinfection in this scenario is the critical initial contamination of a local ulceration site[1,2].

Massive bone defects in the retro or even midfoot due to CN, fractures or dislocations, avascular necrosis, or osteomyelitis may require reconstruction either in a single or sequential intervention based on the patient's clinical characteristics, comorbidities, local or systemic infection, and the severity of the condition. To avoid amputation and its concomitant reported increase in mortality from 38% to 68% at five years, the treatment of osteomyelitis in the context of CN in individuals with diabetes has been previously reported. Pinzur et al. achieved a salvage rate of 95.7% by performing a one-stage resection of osteomyelitic bone, correcting deformity, and using a circular external fixator in patients with CN and osteomyelitis. Similarly, in a retrospective study of 45 patients treated for CN and osteomyelitis, Dalla Paolla et al. concluded

Study performed at the Instituto Jaime Slullitel, Departamento de Cirugía de Pie y Tobillo, Rosario, Argentina.

Correspondence: Gonzalo Alvarez. 2534 San Luis St. Rosario, 2000, Santa Fe, Argentina. **Email:** alvarezgonzalojuan@gmail.com **Conflicts of interest:** none. **Source of funding:** none. **Date received:** April 30, 2024. **Date accepted:** June 04, 2024. **Online:** 30 August, 2024.

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that using a circular fixator and arthrodesis of resected joints represents an alternative to early limb amputation[3-6].

The management of bone loss in the diabetic population with CN should be tailored to individual needs, and there are currently no gold standard or universally applicable treatment algorithms. Using external fixators is likely the preferred fixation strategy for single-stage reconstructions. Despite the existing Anglo-Saxon and European literature that has laid the groundwork for treatment, reports with South American experience are still scarce. Accordingly, the objective of this study is to describe our experience in treating Charcot neuroarthropathy coexisting with concurrent bone infection in a single surgical intervention, treated with external fixation, and report the mid-term radiographic and functional outcomes.

Methods

This is a retrospective case series including six diabetic patients diagnosed with Charcot neuroarthropathy. These patients were consecutively treated at our diabetic foot unit, presenting concomitant osteomyelitis and undergoing a one-stage procedure. The intervention involved ulcer debridement, excision of necrotic bone with sampling for cultures, and specific antibiotic treatment tailored to microbial isolates. Additionally, arthrodesis with an external circular fixator extending beyond the affected site was performed, with follow-up exceeding 18 months. The study received approval from the institution's ethics committee, and all patients or their family members signed the informed consent form.

Only patients diagnosed with diabetic Charcot arthropathy were included. Cases where a polymethylmethacrylate-coated antibiotic-laden intramedullary nail (PMMA) was used with the circular fixator were not excluded. The PMMA served as a non-degradable vehicle for local antibiotic delivery, and the stability of the construct was entrusted to the external fixator.

Retrospective data collection from medical and operative records was conducted to gather demographic information, details related to diabetes metabolic control, procedure specifics, comorbidities, active or recent smoking history, physical examination findings, and clinical outcomes. The presence and location of ulcers, type of deformity according to Brodsky's anatomical classification, arthropathy stage at the time of treatment according to Eichenholtz's classification, and the joints subjected to arthrodesis were documented. Table 1 summarizes the characteristics of these patients[7,8].

The clinical diagnosis of osteomyelitis was based on the fulfillment of one of the following three criteria: (a) an open wound over the deformity with exposed bone and chronic drainage; (b) a history of bone biopsy with positive cultures that, at the time of surgery, was not draining but had abnormally appearing bone in the area previously affected by osteomyelitis; or (c) a history of a previous wound over a deformity with clinically abnormal bone at the time of surgery. The diagnosis required intraoperative cultures in all cases. All diagnoses were confirmed through bone biopsy and examined by a pathologist. A biopsy sample consistent with bone necrosis or inflammatory changes was considered positive for osteomyelitis[5].

All patients underwent anteroposterior (AP) and lateral (L) radiographs of the affected foot and ankle. Relevant information from standard computed tomography (CT) scans, used to measure pre-existing bone defects and the position of the affected joints, was also collected. Magnetic resonance imaging (MRI) images were analyzed for patterns of edema, suspected bone necrosis, fistulous tracts, or deep collections. Arterial Doppler ultrasound with ankle-brachial index (ABI), conducted by a cardiologist experienced in vascular imaging, was included in the preoperative assessment. Patients with an ABI less than 0.9 were not considered candidates until arteriography was performed, providing evidence of perfusion in the angiosomes corresponding to the surgical wound sites.

In the early postoperative period, the assessment of arthrodesis status primarily relied on weight-bearing AP and L radiographs taken during follow-up visits. The radiographs were evaluated by the operating surgeon and a musculoskeletal radiologist.

During the final follow-up visit to evaluate clinical outcomes, we employed the method proposed by Pinzur, considering excellent results when the patient is free of ulcers and infections, capable of walking outside their home, and using commercial shoes with custom insoles. A good result is characterized by the absence of ulcers and infection, the ability to walk outside their home, and the requirement for custom-made shoes or a short orthosis that includes the foot and ankle. A poor result is defined when ulcers or infections

Table 1. Baseline characteristics of the six patients.

	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5	Patient 6
Age	70	62	68	59	50	74
Ulcer	Midfoot plantar	Medial midfoot and hallux	Hallux and medial talus head	Pre ulcerative lesion	Lateral forefoot and midfoot	Lateral forefoot and midfoot
Eichenholtz	3	2	2	3	3	2
Brodsky	1	1	2	2	1	2
Comorbidities	HT	HT, PAD Obesity	HTA, PAD	HT, PAD	HT	HTA, PAD

HT: Hypertension; PAD: Peripheral arterial disease.

persist, requiring a Charcot restraint orthotic walker (CROW) or if a below-the-knee amputation has been performed. Additionally, the duration of external fixation, complications, the need for re-interventions, patient satisfaction (inquiring if they would choose the reconstruction surgery over a below-the-knee amputation), and the distance the patient can walk without difficulties were documented[9].

Surgical technique

The surgical procedure began with the excision of all necrotic-looking bone as the initial step, proceeding until obtaining bleeding bone, followed by sampling at six locations for culture of the remaining bone. Osteotomies were added at the center of rotation of the deformity, if needed for deformity correction, to prepare the articular surfaces and achieve a plantigrade foot position. Percutaneous Achilles lengthening was performed in all patients. After achieving the desired correction, temporary fixation with 1.5 mm pins was implemented. The circular external fixator was systematically placed, applying compression where necessary. Typically, two tibial rings were used, fixed with two pre-tensioned olive wires in the proximal ring, two olive wires in the opposite direction in the distal ring, and connected with four threaded rods. A metatarsal half-ring (attached to the foot with olive wires in opposite directions from the first to the fifth metatarsal, plus one non-olive wire in an oblique direction) was used. The tibial portion of the frame was fixed to the metatarsal half-rings with two threaded rods in the position of maximum deformity correction. A U-shaped adapter was placed on the calcaneus with four pre-tensioned non-olive wires in cases requiring subtalar compression. In cases where a polymethylmethacrylate-coated antibiotic-laden intramedullary nail (PMMA) was concurrently used, it was placed before the circular fixator assembly. Compression was applied intraoperatively and remained unchanged afterward in all cases.

In the immediate postoperative period, patients received intravenous antibiotics adjusted according to microbial rescue for at least one week. Upon discharge, the regimen was switched to oral administration by the infectious disease service based on microbiological rescue. Weight-bearing was restricted for the first 15 days, followed by partial weight-bearing with a walker for eight to ten weeks. The fixator was removed under sedation in the operating room, and patients were placed in an Aircast walking boot for at least 30 days, allowing 30% weight-bearing. Over the following 30 days, full weight bearing was authorized until the removal of the boot upon radiographic evidence of consolidation, stability of the arthrodesis site, and wound healing. Patients were then instructed to use commercial athletic shoes with custom insoles or orthopedic footwear based on the correction they had achieved.

Results

Our report included six patients with a mean age of 63.8 years (range 50 to 74 years) at the time of surgery, classified as stages II and III according to the Eichenholtz classification. The mean follow-up, excluding those who passed away, was 24.2 months (range 18 to 30 months). The results obtained are summarized in table 2.

Table 2. Patients characteristics. Operational details and evaluation.

	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5	Patient 6
Affected Joints	TMT	TMT + CHOPART	TTC	TTC + CHOPART	TMT + CHOPART	CHOPART
Intraoperative cultures	Pseudomona aeruginosa + Aeromona spp + Enterobacter	Estafilococo coagulasa negativo + Bacilo no fermentador	Pseudomona aeruginosa + Enterococcus faecalis	Pseudomona aeruginosa	Escherichia hermanii + Streptococcus agalactiae	Estafilococo coagulasa negativo
Fixator removal	16 weeks	16 weeks	14 weeks	16 weeks	16 weeks	12 weeks
Complications	NO	Ulcer superinfection	NO	NO	NO	NO
Ulcer persistence	NO*	below cuboid needed MIS ostectomy	NO*	NO	NO	NO
Current osteomyelitis	NO*	NO	NO*	NO	NO	NO
Additional procedures	BKA	MIS ostectomy	NO	NO	MIS ostectomy	NO
Footwear		sports shoes with insoles	Sports shoes with insoles	Orthotic shoes	Sports shoes with insoles	Sports shoes with insoles
Accordance	yes*	yes	Deceased (family said yes)	yes	yes	yes
Walk	300 m* with equipment	400 m	400 m (until deceased)	600 m	without limitations	300 m
Follow-Up	deceased at 24 months post-op	24 months	deceased at 34 months post-op	25 months	30 months	18 months

TMT: Tarsometatarsal joint; TTC: Tibiotalocalcaneal; BKA: Bellow-knee amputation; MIS: Minimally invasive surgery. *: retrospective information despite the death of the patient.

Two patients died during the follow-up period due to causes unrelated to Charcot, so only retrospective evaluation of variables was possible for these patients. One of these patients required an infrapatellar amputation 15 months after surgery due to persistent ulcer and over-infection. The external fixator was maintained for a mean of 15 weeks (range 12 to 16 weeks) until removal. One patient required a new debridement and sampling at four weeks from the initial surgery due to the persistence of spontaneous discharge from the ulcer. None of the patients presented infectious complications associated with pin tracts that would have required surgical debridement. Two out of the six patients needed minimally invasive ostectomies after the removal of the external fixator due to the persistence of pre-ulcerative lesions in the plantar region of the cuboid. One of these patients had persistent trophic injury requiring successive sessions of platelet-rich plasma after normalization of ESR and CRP values and persistent negative cultures.

At the end of the follow-up, five out of the six patients were able to walk outside their homes. All patients showed normalization of CRP and ESR values. When interviewed, all patients agreed that they would choose the reconstruction process for their deformity over an infrapatellar amputation. Clinical results, evaluated using the approach proposed by Pinzur, indicate that three patients achieved excellent results, two patients had good results, and one had a poor outcome, which was the patient requiring below-knee amputation (Figures 1-3).

Figure 1. Diabetic patient with CN and concurrent osteomyelitis due to pseudomona. Immediate and last follow-up visit postoperative radiographs depicting good alignment.

Figure 2. Clinical image of the same patient. (A and B) Preoperative photographs depicting unstable valgus of the hindfoot that difficult bracing. (C and D) Postoperative image at 32 months of follow-up.

Figure 3. Pre-and postoperative images at 22 months of follow-up of a CN patient with concurrent osteomyelitis due to Staphylococcus Methicilin resistance.

Discussion

The already complex scenario of reconstructing CN in diabetic patients becomes even more challenging when it coexists with bone infection and loss of stock for fusion under ideal conditions. A local ulceration in a patient with CN should alert them of the imminent risk of osteomyelitis. The bone beneath the lesion site is exposed to bacteria that invade vascular channels, increasing intraosseous pressure and leading to bone necrosis. The less efficient immune response in diabetics is also implicated in the rapidly progressive worsening of these infections, increasing the risk of limb loss. Distinguishing between CN and osteomyelitis usually poses a significant problem as both entities present similar clinical and radiographic findings(10).

In CN coexisting with osteomyelitis cases, surgical debridement combined with systemic or oral antibiotic administration can provide an alternative for limb preservation. Resection of grossly infected or necrotic bone should be performed while preserving as much viable tissue as possible, considering the remaining structures' potential function. The possibility of performing this step together with definitive fixation in a single stage is certainly feasible and has been previously reported in case series. In 2012, Pinzur et al. published a review of 73 patients with CN and osteomyelitis who underwent reconstruction using a circular fixator. At the end of the follow-up, 68 patients (95.7%) maintained ambulatory capacity, with only 4.2% requiring amputation(2,5,11).

Although external fixators are still subject to comfort, surgeon experience, and local practices, there are undeniable advantages in this scenario, contributing to its increasing utilization. The external fixator provides rigid circumferential fixation while allowing dynamic axial compression, enabling surgeons to correct intraoperative errors or postoperative positional loss. It also allows compression through osteopenic bone, a common situation in CN, especially in osteomyelitis. Additionally, there are reports of bactericidal effects associated with the mechanical tension provided by the fixator(12).

While our series is a case report without the possibility of making statistically extrapolatable inferences, there is a trend toward favorable outcomes using the circular fixator. It is essential to highlight that accessory procedures, even after fixator removal, are often a common necessity in diabetic patients, and reporting them as complications aligns with published evidence.

Some complications related to fixator use are frequent, but their clinical relevance is questionable. The most common, with an incidence of 10% to 20%, is a superficial infection at the pin entry site, which typically resolves with local antimicrobials and site care. In our patient series, this did not differ from published data(13).

We believe the results from our case series apply to the previously published literature on the therapeutic modality in question. Despite the substantial variability in outcomes and the potential complexity associated with external fixator use, it is crucial to consider the inherently complicated nature of the treated pathology. We are dealing with patients of equivalent or greater complexity than the pathology itself, and our primary goal is to preserve the affected limb and improve the quality of life, objectives that we have significantly achieved.

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Original Article

Experiences of podiatrists in the delivery of routine foot care with self-management

Beatrice Koh Hwee Jean[1], **Arnold Hu Hanquan**[1], **Leong An-Qi Christel**[1], **Kok Jian Min Jamie**[2]

1. Ng Teng Fong General Hospital, Singapore.
2. National University Hospital, Singapore.

Abstract

Objective: Explore the experiences of podiatrists in the provision of foot care and identify gaps in promoting self-care to their patients.

Methods: This study adopted a qualitative research paradigm comprising semi-structured interviews with 16 podiatrists from diverse clinical settings and varying experiences from February to May 2023. The data was analyzed inductively to develop themes.

Results: Four themes emerged from the data: 1) Provision of nail care service, 2) Perceived reasons for referral for podiatric nail care, 3) Self-management with various patient sub-groups, and 4) Effectiveness of self-management, all from our participants' perspective. Podiatrists agree that pathological nails and high-risk feet warrant continual podiatry care. However, the majority are ambivalent about providing care for non-pathological nails due to fear, indifference, lack of social support, and physical limitations. Interviewees reported the importance of managing patients' expectations of the role of podiatry in nail care from the first visit to avert potential over-reliance on the service. Clear explanations and equipping patients with the appropriate tools helped promote self-management.

Conclusion: This paper examined the complexity of the demand for podiatry nail care services, focusing on podiatrists' perspectives. It emphasized the importance of effective communication with patients to clarify the purpose of podiatry and to ensure sustainable podiatry care for the future.

Level of evidence V; Therapeutic studies - investigating the results of treatment; Expert Opinion.

Keywords: Nail diseases; Qualitative research; Self-management.

Introduction

Onychauxis and onychomycosis are some of the many nail issues affecting older peoples' social and emotional well-being[1-4]. Historically, podiatrists have been involved in nail cases, diabetic limb salvage, and musculoskeletal conditions. With the limited amount of podiatrists and rising demand for podiatric services, some governments have reconsidered podiatrists' scope of practice and prioritization of services. The United Kingdom (UK) has adopted strategies to encourage less dependence on healthcare institutions for nail care, encouraging patients to self-care instead[5,6].

Singapore's podiatry profession was established in 1993. According to an informal survey conducted by the Podiatry Association Singapore in 2021, all 127 podiatrists were trained overseas due to lacking a local program. Podiatric care is available in public and private healthcare, with private care offering non-subsidized but faster appointments. In Singapore, non-healthcare providers (pedicurists) provide basic foot care services.

Singapore's aging population amplifies the urgency to optimize podiatry services, especially with the current shortage of podiatrists. Singapore lags in podiatrist-to-population ratio compared to global standards[7]. In 2021, the Singapore population stood at a ratio of 2 podiatrists per 100,000 people. Comparatively, New Zealand has a ratio of approximately 8.5 podiatrists per 100,000 people, whereas Australia and the UK estimate 20 podiatrists per 100,000 people[7].

Study performed at the Ng Teng Fong General Hospital, Singapore.

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To date, little is known about the current experiences among podiatrists in Singapore regarding managing toenail conditions and the effectiveness of educating patients on self-management. Therefore, this study aims to explore the experiences of Singapore's podiatrists in providing foot care and identify gaps in promoting self-care.

Methods

Design

Inspired by the social-ecological model, this study explored factors related to nail care through semi-structured interviews. This data collection method allowed participants to express themselves freely and ensured no omission of important topics. The interview guides were tested on two podiatrists not part of the recruitment. Based on their feedback, the topic guide was adjusted accordingly. Ethical approval from the NHG Domain Specific Review Board (Ref: 2022/00129-SRF0001) was obtained.

Recruitment and procedure

Sixteen interviews were conducted from 23rd Feb 2023 to 10th May 2023 (Table 1). Podiatrists were recruited from acute to subacute care via convenience sampling to gain a fuller perspective.

The participant must be a podiatrist working in Singapore who is willing to be interviewed to be eligible for the study. Recruitment emails were sent to podiatrists to invite them to participate in the interview.

Interviewees were briefed verbally and in writing. The exploratory nature of the discussion was emphasized, and participants were given the option of withdrawing or ending the interview at any point. The interviews were conducted in English by three investigators (BK, AH, and CL), lasted 27 to 61 minutes on average (mean: 36 mins), and were facilitated via Zoom. Investigators conducted the interviews in private rooms, and participants were advised to do the same to ensure confidentiality. Field notes were taken, and interviews were audio-recorded, transcribed verbatim, and anonymized using pseudonyms.

Data analysis

This study adopted an interpretive research paradigm to analyze the podiatrist's decisions and perspectives on general care.

Transcripts were coded using inductive and deductive approaches, with thematic content analysis conducted with Excel. All four researchers were randomly allocated to transcribe and code transcripts to ensure impartiality. Researchers carefully read the transcript to familiarise themselves with the content before performing line-by-line analysis to identify emerging themes. Themes and sub-themes were derived from the analysis. After coding the transcript, investigators met to discuss the coding through an iterative consensus-building process. With a codebook, re-coding was done independently with a deductive approach while ensuring the codebook was extensive and reflective of each transcript analyzed. Member checks were done to ensure inter-coder reliability and validity of the data. Data saturation was reached with the number of interviews performed. Study findings were returned to participants who were agreeable to be contacted again for comments and clarifications.

Table 1. Participant demographics

Participant	Sex	Length of time in podiatry (years)	Duration of the interview (mins)	Age range (20-30/31-40/41-50/51-60)	Institution (Primary/Tertiary/ Private)
1	F	6 -12	27	31-40	Tertiary
2	F	2 - 6	33	20-30	Tertiary
3	F	>12	30	41-50	Tertiary
4	F	0 - 2	30	20-30	Tertiary
5	F	2 - 6	42	20-30	Private
6	F	2 - 6	59	20-30	Tertiary
7	F	2 - 6	33	20-30	Tertiary
8	F	>12	45	31-40	Tertiary
9	F	6 -12	33	31-40	Primary
10	M	6 -12	30	31-40	Private
11	F	> 12	25	31-40	Primary
12	F	6 - 12	61	31-40	Tertiary
13	M	> 12	25	31-40	Private
14	F	2 - 6	48	20-30	Primary
15	M	0 - 2	34	20-30	Primary

Researcher reflexivity

As podiatrists within the acute setting, we were interested in understanding how podiatrists' perspectives may corroborate in general care and self-management. Acknowledging the potential for a dependent relationship between researchers and interviewees, the researchers established clear boundaries, assured participants confidentiality, and emphasized non-judgmental inquiry. As podiatrists, the researchers could empathize with participants' experiences, which might influence the questioning direction.

Results

Four major themes were identified: (1) Podiatrist perception of nail care services, (2) Perceived reasons for patient presentation for podiatric nail care, (3) Podiatrist perception of self-management on various groups of patients, and (4) Podiatrist perception regarding the effectiveness of self-management. It should be noted that themes and sub-themes are distinct yet mutually related.

Theme 1: Podiatrist perception of nail care service

Podiatrist value in nail care

Podiatrists know they are valued in healthcare as the medical profession that looks after nails. It is in their skill set to help patients with foot problems and, in some cases, safeguard them from infection and amputations. They prefer treating pathological nails, which adds value to their patients.

> "I think we are the best people to treat pathological nails. Because if a nail is truly pathological, it is a skill to be able to cut a thick onychogryphotic nail, to cut an ingrown toenail in a way to encourage it to grow properly and not cause the patient harm or pain." (P08/F)

> "I know it's too long and too thick, and there's no other profession that can do it; we actually save a toe. Unknowingly, the hard work does save, save feet." (P01/F)

Podiatrist view on non-pathological nails

However, most podiatrists feel that they do not value dealing with non-pathological nails and, in some cases, prefer not to see those cases. Three participants used strong words like "hate" or something that needs to be "get rid of". They likened the service of non-pathological nails to a non-medical need that should not require podiatrist intervention.

> "I hate personally cutting nails, it's because nail growing is not an abnormality. It's normal, it's normal for nails to grow long, just like how your hair grows long, so you know there is no need for a special service for you to trim your hair, so why is there a need for professional and medical help to trim your nails?" (P16/F)

Most podiatrists believe that non-pathological nails are a social problem that their profession should not address but someone else.

> "I'm here to treat nails that are medically indicated to treat... trouble reaching their nails, then that's when it becomes more of a social issue" (P15/M)

> "Podiatrists are medical professionals, so we should really be only treating nails that have an actual issue, so pathological conditions or high-risk patients... There should be a step-down care below to offer that service, or like a social service" (P09/F)

Podiatrist tension in value towards nail care

Some podiatrists feel that some in the profession do not appreciate their value in nail care provision and may be detrimental to themselves and the profession. A disparity exists among podiatrists regarding this subject.

> "I think sometimes we do ourselves a disservice by thinking that is it something so beneath us to be doing nail care" (P08/F)

> "I feel as though a lot of podiatrists are trying to practice at the top tier of their license, but along the way, when they are trying to do all the sexy stuff... especially in the hospitals, I feel as though as there might be predilections not to want to treat nails anymore even if there are problems with those nails, and I think that's an issue." (P15/M)

In saying that, most podiatrists still educate and treat nails but try not to prioritize this over other podiatric services (e.g., wound care).

Theme 2: Perceived reasons for patients' presentation for podiatric nail care

Podiatrists shared the perceived reasons why patients attend for general nail care. The main reasons include (1) Personal barriers faced by patients, (2) Lack of support from family members, and (3) Low motivation by patients to self-manage.

Personal barriers faced by the patient

All podiatrists mentioned the physical barriers as to why a patient may present at the podiatrist due to factors such as "can't reach their feet, can't see" (P12/F). Some patients present if they have issues getting instruments that help with the nails, fear trimming their toenails, or have medical conditions such as diabetes.

> "Some of them because they are elderly patients, and they can't reach their toes, and it becomes like such a lame limiting factor, but it's real." (P04/F)

In participant four quote, while she understands the rationale patients present, there lies some negativity in seeing non-pathological cases.

Lack of support from family members

Most podiatrists acknowledge that family members/ domestic helpers play a part in managing non-pathological nails. In cases where there is a "lack of family members to help" (P13/M) or when the patient refuses family help, these cases present themselves to the clinic.

"Some of them social issues, so nobody to cut for them. There's elderly who live alone, there's elderly who are demented and refuse to allow next of kin to cut but only want to come here and cut." (P01/F)

Low motivation by the patient to self-manage

Some patients decline to look after their foot condition despite being educated by podiatrists on how to do so. This group of patients would rather seek podiatric intervention as it has become routine for them.

"So that's the biggest barrier, is that they are not motivated to do it, systematically and routinely. They just want to come in every few months and not bother about it. They want somebody else to do it." (P11/F)

"The negative aspect is some patients are just so used to it. You know so they just don't even want to try. And they are so used to the routine" (P12/F)

Theme 3: Podiatrist perception of self-management with various patient sub-groups

Given the limited number of podiatrists in Singapore, most podiatrists strive to educate the patients who present with general care. The education focuses on empowering patients to self-manage with the eventual discharge goal. The actual education may differ based on the perception of self-management based on the type of patient group: (1) New patients, (2) Current patients.

New patients

With newer patients coming in, most podiatrists tend to find them more impressionable and are more open to self-management.

"I think those who see you for the first time who doesn't have any prior knowledge about podiatry and what we do. So they are more receptive when you tell them 'this kind of nails I cut for you this one time, but after that you have to file it yourself" (P06/F)

Most podiatrists will set and manage patient expectations on the consult with the intent of discharging cases that are low-risk general care. The discharge often happens within the first consultation, and "most patients don't return for another consult" (P11/F).

Current patients

For mid-to long-term patients, most podiatrists look into lengthening appointment intervals and encouraging them to seek others for help between appointments. Participant 6/F calls it the "opportunity for them to realize that it is easier to manage themselves". Some patients may require podiatry interventions despite performing some self-management as they are still "learning how to do the right thing" (P03/F).

Whereas, there are patients who have been taught how to self-manage and still come back as they "are just here to trim the toenails…heard it (self-management) thousand and one time and have never ever done it, so you know they are not going to do it" (P02/F). 60% of interviewed podiatrists feel obligated to see patients they believe don't require podiatric care due to fear of complaints.

Two participants (P12/F and P01/F) noted that some podiatrists assume routine patients need appointments without asking if they're necessary or if self-management could suffice. This prolongs patients' stays in the healthcare system.

Theme 4: Podiatrist perception of the effectiveness of self-management

Advice for self-management

Podiatrists use an amalgamation of methods to educate their patients on self-care. Nearly all demonstrated nail care techniques such as filing, trimming, and clearing nail sulci to accompany their explanations. They established that it was important to have patient-centric self-care advice, such as overcoming physical barriers and purchasing the appropriate tools.

"I will try to give certain alternatives so that they can just pick what is, at least there must be something they can do right. If I give them one solution and it's too difficult for them, then they just neglect the whole thing. So I let them choose what is easiest for them. " (P05/F)

"Most of it is teaching them alternative methods like, some of them might say, "I have this problem but nobody taught me how to do it", so a lot of it is teaching them easy access ways…put your foot on the stool or use a long-handled file" (P11/F)

75% of interviewees issued supplemental aids in videos, written instructions, or leaflets as a take-home reminder of the advice given. While podiatrists found the reference materials helpful, these take-home reminders have limitations. Older people faced technical difficulties and were less responsive to videos. Some podiatrists doubt that patients read the leaflets.

"The video is helpful if they watch it, but in our busy clinics it's a bit challenging… and also our patients are quite old so it is quite hard to get them to scan the QR code." (P01/F)

Tools for self-management

Four interviewees issued appropriate tools to patients to make it more convenient for patients to trial self-care.

"So with a tool that has been provided for them, so hopefully that will help to empower them to manage their own toenails, e.g., regular filing, that reduces the need for the visit." (P03/F)

Effectiveness towards self-management

All podiatrists interviewed reported that most patients were receptive to self-management advice. Patients associated with a higher likelihood of self-management were those with pain, cognitively able, physically able to reach their feet and have good social support at home. Nevertheless, most of the interviews reached a similar conclusion – that the patients' mindset was the key determinative factor of self-management.

"I think it's also how enthusiastic patients are, how proactive they are in taking charge of their nails. Sometimes we can try a lot of means, but sometimes they are not encouraged to do so." (P07/F).

"And I think it all boils down to their self-motivation also, whether they are motivated to care for themselves or whether they just want to depend on someone else to care for them." (P10/M).

Discussion

This paper showed that podiatrists understand the value of providing nail care. This is supported by Farndon et al.[8] that having a podiatrist to treat nails and keratotic lesions can help sustain foot health and reduce pain in 75% of patients. Menz[9] further emphasized the importance of nail care for older individuals' foot health, although toenail cutting is often considered less critical. However, our participants suggested that podiatrists may not significantly value trimming non-pathological toenails, which aligns with Vernon et al.'s recommendation that foot care is valuable without necessarily requiring professional intervention[10].

Menz[9] and Woodrow et al.[11] highlighted the strain on podiatrists' resources and suggested the potential involvement of nursing staff to address this issue. The study by Wallis et al.[12] on declining podiatrist numbers in England underscores the potential challenges faced in Singapore, where podiatrists were trained. Consequently, prioritization of cases, as noted in our study, becomes essential, with some podiatrists expressing a preference to delegate non-pathological nail cases. The success of transferring nail care responsibilities to other medical or social sectors varies across countries[10,13,14].

Patients typically seek podiatric help due to physical limitations, lack of familial support, or low motivation for self-management. Miikkola et al.[3] suggested that older individuals who seek foot care help do not involve their immediate family, possibly due to the perception that foot care is intimate and prefer to entrust it to healthcare professionals. Our study indicates that new patients are often receptive to self-managing nail-related conditions, aligning with recommendations for early encouragement of self-management and safe discharge[15-17]. Dineen-Griffin et al.[18] highlighted the need to provide patients with the knowledge, resources, and self-efficacy so that they can manage their nails. However, implementing self-management strategies may be challenging, as some patients require time to adjust and may seek podiatric care continually without any behavioral changes[19,20]. Additionally, two participants shared that implicit biases may hinder self-management education, prolonging patients' reliance on the healthcare system[21].

Our participants highlighted the importance of patient-centered education strategies, which may include verbal explanations and demonstrations to enhance self-management skills. Literature showed that there is no universally superior communication method[22] and supported the need for tailored approaches to self-management[18,23,24] by recommending various communication methods to maximize learning[22]. However, education alone may not lead to behavioral change, necessitating ongoing discussions and support from healthcare professionals[25,26]. Instrumental and psychosocial support from family members is associated with better self-management[26,27]. Ultimately, patients must possess the knowledge, skills, and confidence to manage their health to potentially reduce reliance on podiatry services and lessen the healthcare financial burden[3,28].

Strengths and limitations

The consolidated criteria for reporting qualitative research (COREQ) was used in this study to ensure its rigor[29]. To the authors' knowledge, this is the first study done in Singapore that seeks to understand podiatrists' views on nail care. Participants shared their opinions freely throughout the interview. The population of podiatrists interviewed was considered representative of the private and public sectors of Singapore.

This study considered podiatrists' perspective of nail care in Singapore. More can be done to discover patients' and families' perspectives on adherence to nail self-management habits. This will shed light on any differences between the clinicians' and patients' perceptions and expand the understanding of the current motivations and barriers patients face in foot care.

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Original Article

Magnetic resonance imaging findings of plantar venous thrombosis: a comparative study with Doppler ultrasound

Marcelo Damaso Maruichi[1], Fernando Ometto Zorzenoni[1], Julio Brandão Guimarães[1,2,3], Thomas M Link[2], Alípio Gomes Ormond Filho[1], Caio Augusto de Souza Nery[4,5], Marcelo Astolfi Caetano Nico[1]

1. Department of Musculoskeletal Radiology, Fleury Medicina e Saúde, São Paulo, SP, Brazil.
2. Department of Radiology and Biomedical Imaging, University of California, San Francisco, CA, USA.
3. Department of Radiology, Universidade Federal de São Paulo (UNIFESP), Sao Paulo, SP, Brazil.
4. Orthopaedics and Traumatology Department – Universidade Federal de São Paulo (UNIFESP), São Paulo, SP, Brazil.
5. Foot and Ankle Service – Escola Paulista de Medicina, São Paulo, SP, Brazil.

Abstract

Objective: Analyze magnetic resonance imaging (MRI) findings, demographics and clinical data in patients with plantar venous thrombosis (PVT).

Methods: A retrospective study screening patients with PVT, diagnosed with color Doppler ultrasound, who also underwent MRI of the foot and ankle. In the post-contrast MRI sequences, the intravascular filling defect was analyzed, and in the non-contrast MRI sequences, the diameter of the foot vessels was analyzed, and perivascular edema was documented. MRI exams from a control group without PVT were also analyzed.

Results: Sixty-one cases and 204 controls were included. The lateral plantar veins were the most frequent location in the foot with PVT (63.9%). In all post-contrast sequences, an intravascular filling was seen. In the case group, veins had a significantly greater diameter compared to controls ($p < 0.05$), and perivascular edema was observed in all cases (100%). A history of trauma/mechanical overload of the foot was documented in 83% of the patients ($p < 0.001$).

Conclusion: Our results showed that the lateral plantar vein was the most frequent location of PVT. An intravascular filling defect on post-contrast MRI sequences was seen in all PVT cases. Compared to the control group, all vessels had a greater diameter in the case group, and perivascular edema was observed in all cases. Our results also suggest that a clinical history of trauma or mechanical overload (physical activities) in the foot and ankle may be one of the causal factors of this pathology.

Level of evidence III; Therapeutic studies - investigating the results of treatment; Retrospective comparative study.

Keywords: Magnetic Resonance Imaging; Venous thrombosis; Thrombosis; Foot and ankle.

Introduction

Plantar venous thrombosis (PVT) is an underdiagnosed cause of pain on the plantar surface of the foot. It is characterized by the formation of a thrombus within the deep plantar veins, and its clinical symptoms are nonspecific: usually pain, local edema, and tenderness to palpation, which may be associated with difficulty in gait and functional loss. This symptomatology may be confused with other more frequent causes of pain syndrome on the plantar surface of the foot, such as plantar fasciitis, musculotendinous injuries, stress fractures, plantar plate injuries, bursitis, and neuromas[1].

Drainage of the deep venous system of the foot starts from the digital plantar veins, which originate on the plantar surface of the toes, uniting to form the metatarsal veins located in

Study performed at the Foot and Ankle Service – Escola Paulista de Medicina, São Paulo, SP, Brazil.

Correspondence: Julio Brandão Guimarães. 185 Berry St, Suite 350, San Francisco, CA 94158, USA. **Email:** julio.BrandaoGuimaraes@ucsf.edu. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** June 14, 2024. **Date accepted:** July 16, 2024. **Online:** August 30, 2024.

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the intermetatarsal spaces, which then form the deep plantar venous arch. They follow the plantar arterial arch and give rise to the medial and lateral plantar veins, which unite behind the medial malleolus to give rise to the posterior tibial veins[1-4].

The pathophysiology of PVT is still controversial. In addition to sharing common risk factors for thrombosis in any part of the body, such as recent surgery, trauma, infection, neoplasms, and oral contraceptives, mechanical stress on the plantar surface of the foot can cause microtrauma and damage to the endothelial wall, acting as a key factor in Virchow's triad (hypercoagulability, venous stasis, and endothelial injury) and activating the blood clotting cascade[5].

Doppler ultrasound is the most used imaging modality to diagnose thrombosis and is an accessible and inexpensive method, therefore are some limitations to its use, the fact that this method is examiner-dependent, the access of veins that are deeply located, and frequently the study of the plantar veins is not part of the routine protocol for investigating foot pain[2]. On the other hand, magnetic resonance imaging (MRI) can assess all foot structures simultaneously and three-dimensionally, with good differentiation between structures. In addition, intravenous contrast facilitates visualization of plantar thrombi through imaging of vascular filling defects. Computed tomography provides limited assessment of the soft tissues of the foot and may not be considered for this indication. PVT has been believed to be a relatively innocuous entity. However, significant complications are associated with this condition, notably including the extension of the thrombus to the proximal veins and the development of pulmonary thromboembolism (PTE), underscoring the potential severity and clinical significance of these complications, necessitating heightened attention and prompt intervention [6-8].

Considering the probable underdiagnosis of this condition and the fact that MRI is frequently used in the investigation of painful foot syndrome, the purpose of this study is to analyze MRI findings, demographical and clinical data in patients with PVT, confirmed with color Doppler ultrasound.

Methods

Study design and patient selection

A retrospective search was performed on exams from 2017 to 2022 using the institution's PACS system (VR12, Phillips) by screening patients who also underwent contrast-enhanced MRI of the foot and ankle within seven days of the Doppler ultrasound examination with the diagnosis of PVT.

The inclusion criteria were patients with a clinical history of acute foot pain and thrombosis, as confirmed by a color Doppler ultrasound study-considered the gold standard, defined by non-compressible venous segment and absent color flow.

Superficial phlebitis cases, patients with diabetes, vasculopathy, vascular malformations, infection, postsurgical cases, and unsatisfactory technical quality were excluded.

Therefore, 86 cases were obtained. Twenty-five cases were excluded: Fifteen cases with superficial phlebitis, five cases with vascular malformations, four cases with unsatisfactory technical quality, and one case of osteomyelitis.

The final case cohort included 61 patients that met all inclusion and exclusion criteria for PVT. All patients had a clinical history of acute-recent foot and/or ankle pain.

Control group

A control group was also selected, matched for age, sex, and body mass index (BMI), who underwent contrast-enhanced MRI of both feet and ankles without thrombosis on imaging studies during the same period, excluding postsurgical cases, diabetic feet, cases with artifacts and/or cases with vasculopathy.

For the control group, 242 cases were initially selected: all without any imaging signs of thrombosis and no clinical findings suggestive of thrombosis. After a detailed review, seven cases with vasculopathy, six cases with infection impairing the review of all vascular segments, and five cases with partial amputation of the foot/ankle were excluded. Finally, 224 patients were included in the control group.

Demographics and clinical data

Clinical information was collected from questionnaires completed by the patients before the exams. These questionnaires included information on sex (male and female), age (years), weight (kg), height (m), and clinical symptoms (pain, pain and swelling, pain and paresthesia, nodulation, paresthesia) at the time of the examination and duration of symptoms (days). The questionnaires also documented the use of oral contraceptives (yes vs. no), comorbidities (diabetes, hypertension, cancer, cholesterol, neurological disease, thrombophilia, and postoperative), history of recent physical exercise, and recent foot trauma (yes vs. no).

Ultrasound acquisition

A HD11 XE ultrasound machine (Philips, Andover, MA, USA) with a high-resolution 7.5–12MHz transducer was used. All the main foot and ankle veins were imaged with high-resolution multi-linear array transducers, and the location and extent of thrombosis were recorded in detail. The Doppler ultrasound was the gold standard: In ultrasonography, thrombosis was defined by absent flow on color Doppler study with no vessel compressibility (Figure 1) as previously described[9].

MRI acquisition

All included patients underwent a complete contrast-enhanced MRI of the foot or ankle. The exams were performed using a 1.5 Tesla MRI system (GEM, GE Healthcare) with a dedicated foot and ankle coil (GE Healthcare). In the ankle exams, the patient was in a supine position with the foot perpendicular to the table axis. In the foot exams, the patient was a prone position with the foot in plantar flexion using the same coil. The routine protocol of the ankle included

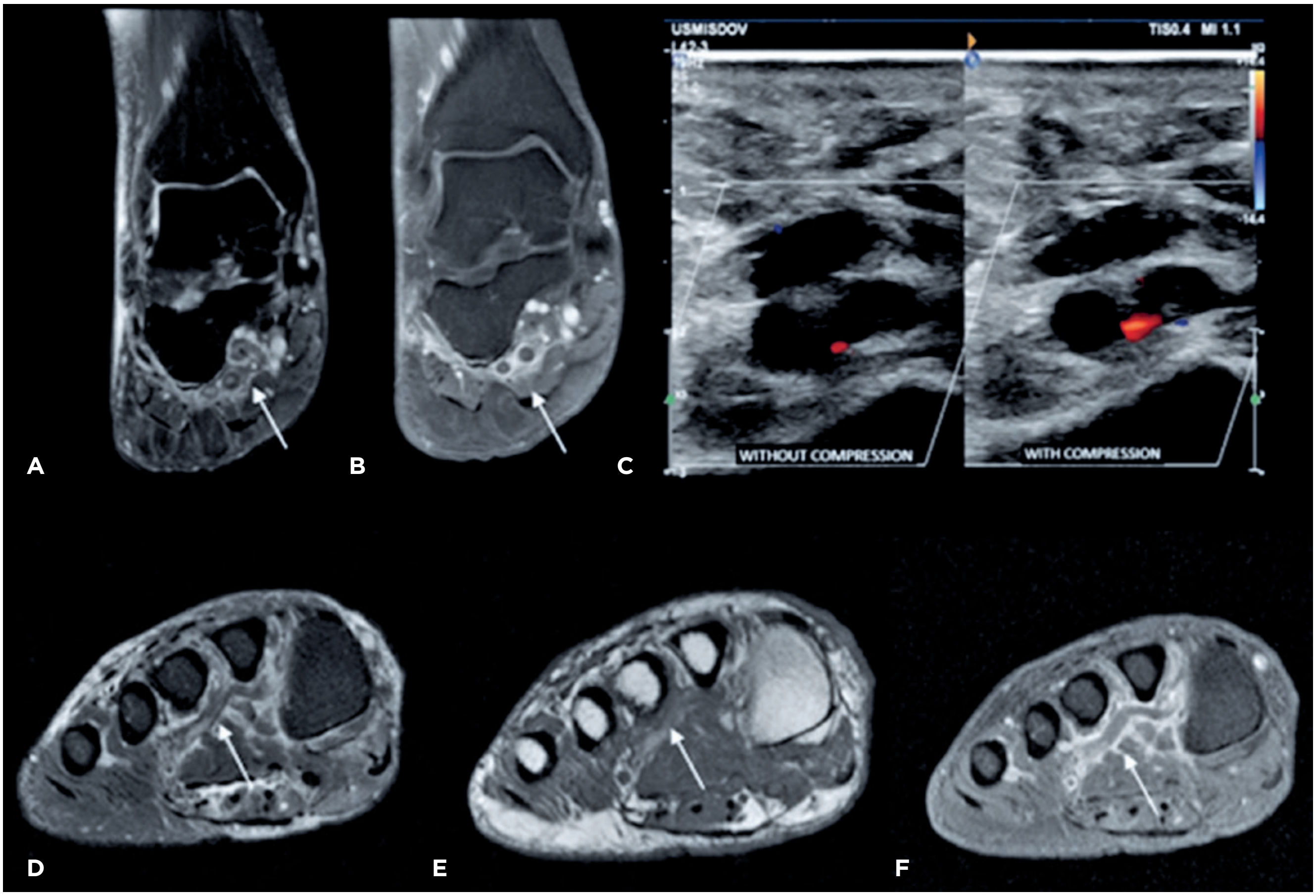

Figure 1. MRI sequences in a 47-year-old woman with pain for seven days. (A) coronal fs T2-w sequence of the ankle shows an enlarged lateral plantar vein and perivascular edema (open arrow). (B) coronal postcontrast fs T1-w sequence of the ankle shows a filling defect lateral plantar vein (open arrow) with enhancement of the perivascular planes (arrow). (C) ankle ultrasound showing echogenic material inside the bifurcated lateral plantar vein with no flow on the Doppler study, without the compression maneuver on the left, related to lateral plantar vein thrombosis. (D) coronal fs T2-w sequence of the midfoot shows plantar arch enlargement and perivascular edema (arrow). (E) coronal T1-w sequence of the midfoot shows material with a high signal within the plantar arch (arrow) associated with obliteration of the perivascular planes. (F) coronal postcontrast fs T1-w sequence of the midfoot shows a filling defect by contrast of the plantar arch with material with an intermediate signal inside that corresponds to the thrombus (arrow) associated with obliteration and enhancement of the perivascular planes.

T1- and fat-saturated (fs) T2-weighted (-w) fast spin echo (FSE) sequences in the axial and sagittal planes as well as a coronal fs T2-w FSE sequence. The foot protocol included T1- and fs T2-w FSE sequences in the coronal and axial planes and sagittal fs T2-w sequences. In addition to this basic protocol, intravenous paramagnetic contrast (gadoteric acid - Dotarem®, Guerbet) was used in all cases. The MRI sequence parameters are described in Tables 1 and 2.

Image analysis

All MRI imaging studies were analyzed separately by two radiologists specialized in musculoskeletal radiology with ten and seven years of experience (MDM and FOZ, respectively).

Post-contrast MRI

In the post-contrast MRI sequences, the intravascular filling defect was analyzed and defined as an intravascular filling defect with absent signal intensity surrounded by high-signal intensity from flowing blood (Figures 1-4).

Non-contrast MRI sequences, the diameter of the foot vessels was analyzed. Posterior tibial, fibular, anterior tibial, medial plantar, lateral plantar, plantar arch, and intermetatarsal veins (Figure 5) were measured in the largest transverse diameter of the vessels in fs T2-w sequences using the Philips Carestream VR 12 PACS system measurement tool. The diameter of the anterior and posterior tibial and fibular veins was measured in the axial sequence of the ankle in the

Table 1. MRI sequence parameters of the ankle

Ankle	FOV	Thickness (mm)	Spacing (mm)	Slices	RT (ms)	ET (ms)	Matrix pixels	NEX	Bandwidth
Sagittal T1	15	4	0.4	14	485	13	348 x 256	2	41.67
Sagittal T2 Fat sat	15	4	0.4	14	2604	70	256 x 224	4	41.67
Axial T1	16	4	0.4	22	600	14	351 x 192	1	31.25
Axial T2 Fat sat	15	4	0.4	14	3823	60	256 x 224	4	41.67
Coronal T2 Fat sat	16	4	0.8	20	3627	60	256 x 224	4	31.25
Coronal OBL Fat sat	16	3	1	24	2554	45	252 x 252	2	35.71

FOV: Field of view; RT: Repetition time; ET: Echo time; mm: millimeters; sat: saturation.

Table 2. MRI sequence parameters of foot

Foot	FOV	Slice thickness (mm)	Spacing (mm)	Slices	RT (ms)	ET (ms)	Matrix pixels	NEX	Bandwidth
Sagittal T2 Fat sat	15	3.5	0.5	20	3202	60	256 x 256	4	31.25
Coronal T2 Fat sat	11	3	0.5	24	4114	60	256 x 224	4	25
Coronal T1	11	3	0.5	12	418	9	288 x 224	2	31.25
Axial T2 Fat sat	12	3	0.3	12	2062	70	256 x 224	4	19.23
Axial T1	12	3	0.3	12	394	9	288 x 256	2	31.25

FOV: Field of view; RT: Repetition time; ET: Echo time; mm: millimeters; sat: saturation.

bimalleolar plane (where we visualize the two malleoli in the axial sequences). The diameter of the medial and lateral plantar veins was measured in the coronal plane of the ankle at the midpoint of the distance between the bimalleolar plane; the plantar arch was measured in the coronal plane of the midfoot in the plane of its longest longitudinal axis, and the intermetatarsal veins were measured in the coronal plane of the forefoot at the midpoint between the plantar arch and the transition of the intermetatarsal veins with the interdigital veins. All measurements of vascular diameter were made in millimeters (mm). The analyses were performed separately by two radiologists and inter- and intraobserver correlation was also evaluated.

Also, in the non-contrast MRI fs T2-w sequences, the presence or absence of perivascular edema (defined as a halo of high signal in the fs T2-w sequences around the vessel) was documented in all vascular segments of both groups (Figures 2-4).

Statistical analysis

Data analysis was performed using descriptive statistics (mean, standard deviation, median, minimum, maximum, frequency, and percentage) using R version 4.2.0 (copyright © 2022, The R Foundation for Statistical Computing). Case and control groups were compared using the chi-square test (categorical variables) or the Mann-Whitney test (numerical variables). The level of significance considered in the analyses was 5%. Interobserver agreement was assessed using the intraclass correlation coefficient (ICC).

Results

Demographics and clinical findings

Of the 61 patients in the case group, 26 were women, and 35 were men. The mean age was 49.2 years (36–63), and the mean BMI was 26.3 (24.5–30). Thirty-one patients had thrombosis on the right side, and 30 had thrombosis on the left side.

In the control group, there were 131 women and 93 men, with a mean age of 47.4 years (36–57.2 years) and a mean BMI of 27.3 (24–29.8). No significant differences were found between the two groups regarding age, sex, and BMI ($p > 0.05$), as shown in Table 3. The right side was used for comparison in 107 of them, and the left side was used for comparison in 117.

All patients in the case group presented with a clinical history of acute foot and ankle pain. The mean duration of symptoms in patients with thrombosis until the Doppler ultrasound was performed was 8.5 days, with an interquartile range between 6 and 10 days and a median of seven days. The mean duration until the MRI was performed after the ultrasound was five days, with an interquartile range between 1-7 days.

Of the case group, 83.6% (52/61) reported a history of recent physical exercise or recent foot trauma; most patients reported pain as the main clinical symptom (86.9%, 52/61). An association with swelling was seen in 6.5% of cases. Table 4 shows the distribution of categorical variables between the case and control groups. Trauma and recent physical exercise in the foot demonstrated a statistically significant association

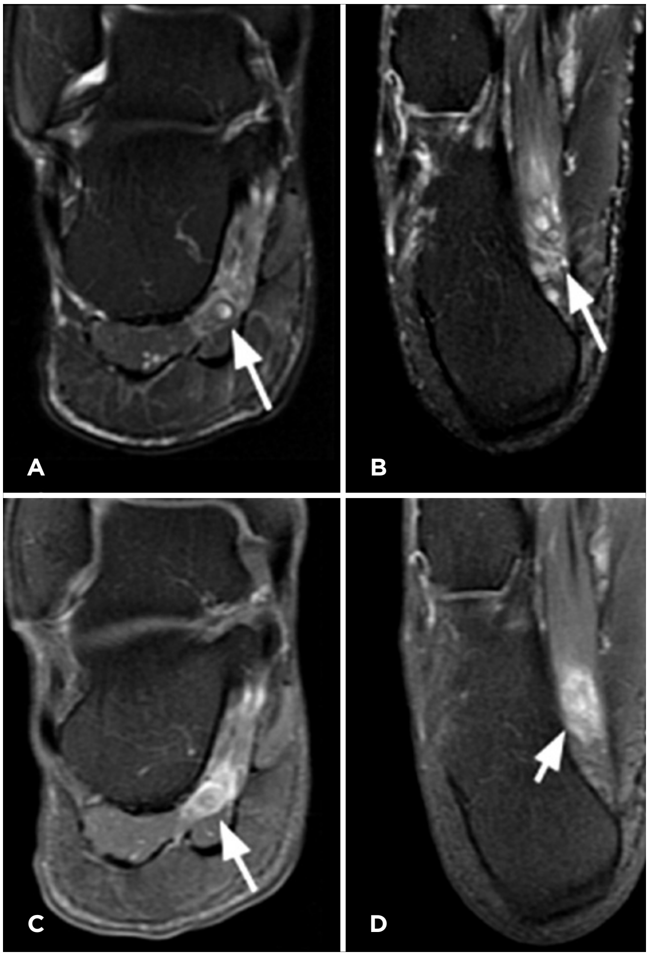

Figure 2. Lateral plantar vein thrombosis in a 65-year-old woman with plantar pain and tingling sensation for two weeks. Frequent Muay Thai classes three times per week. Hindfoot coronal (A) and axial (B) fs T2-w sequences show proximal lateral plantar enlargement and perivascular edema (arrow). Hindfoot coronal (C) and axial (D) fs T1-w postcontrast showing filling defect of the proximal lateral plantar vein, related to thrombosis (arrow).

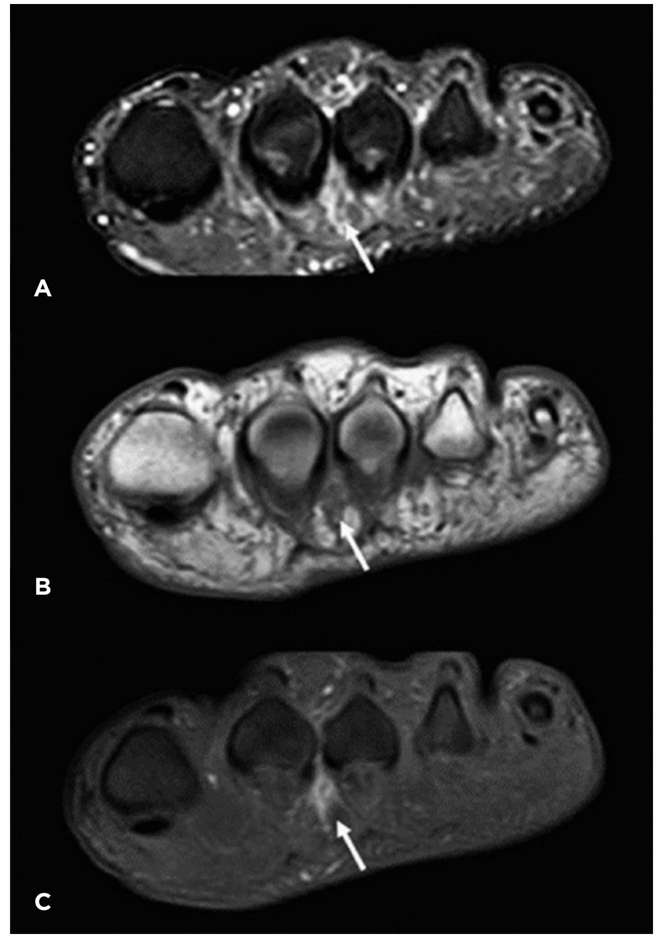

Figure 3. MRI sequences in a 51-year-old woman with pain in the plantar surface of the forefoot for ten days after a marathon. (A) Coronal fs T2-w of the forefoot shows enlargement and perivascular edema in the second intermetatarsal vein in the plane of the metatarsal neck (arrow), with obliteration of the adjacent fat planes. (B) Coronal T1-w sequence of the forefoot shows obliteration of the fat planes of the second interspace in the plane of the metatarsal neck (arrow). (C) Coronal postcontrast fs T1-w shows a filling defect in the contrast study (arrow) of the intermetatarsal vein of the second associated space and edema with contrast enhancement of the perivascular planes.

with thrombosis ($p < 0.001$). Also, the relevant comorbidities, such as diabetes mellitus, arterial hypertension, metabolic syndrome, hypercholesterolemia, smoking, thrombophilia, neoplasia under treatment, and chronic kidney disease, were documented, but no statistical difference between the groups was found ($p = 0.178$).

MRI findings

Of the vessels affected by thrombosis, 39/61 (63.4%) were part of the lateral plantar veins, 21/61 (34.4%) of the intermetatarsal veins, 9/61 (14.8%) of the plantar arch and five or less were other vessels affected (fibular, interdigital, medial plantar, and posterior tibial). In 14 patients, one or more vessels were affected. In 18 cases (22.5%), proximal extension of the thrombus to the calf veins was shown.

On MRI, the veins with thrombosis observed on Doppler ultrasound presented with intravascular filling defect in all cases (100%) in the post-contrast enhanced sequences.

The perivascular edema was observed in all cases (100%) on non-enhanced sequences. Also, compared to the control group, all vessels had a greater diameter in the case group (Table 5); differences were most pronounced in the lateral

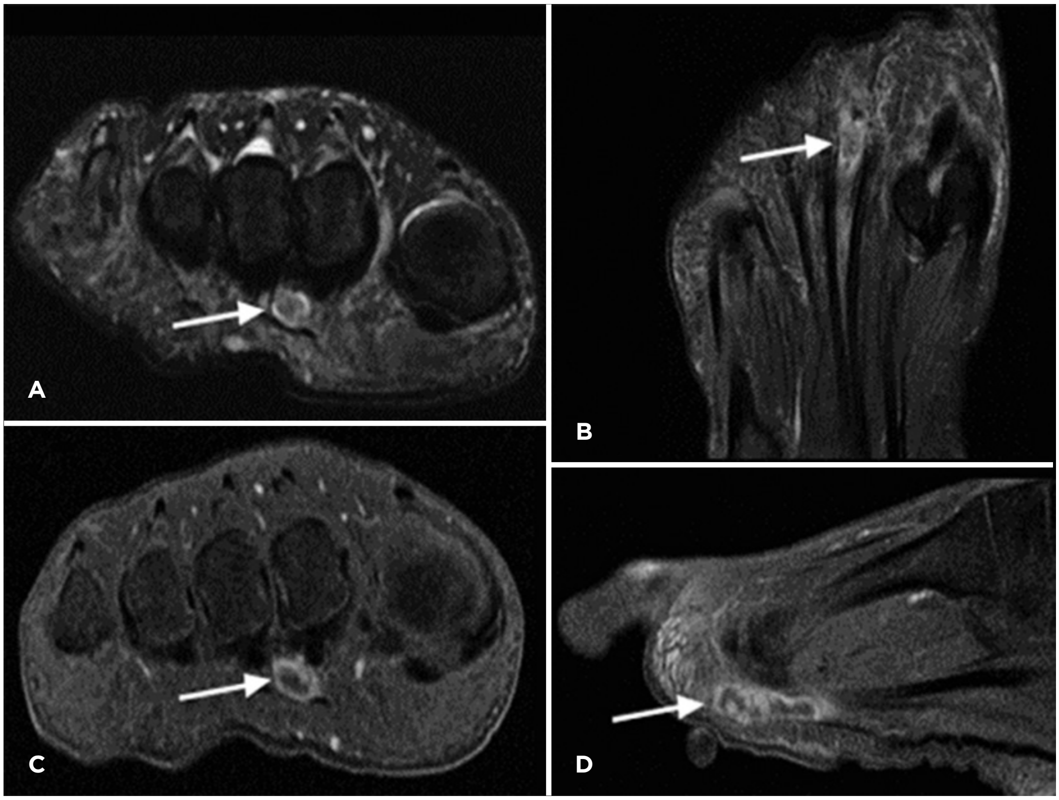

Figure 4. MRI sequences in a 47-year-old woman who practices regular walks with plantar pain which is worse while walking. Coronal (A) and axial (B) fs T2-w sequences show enlargement and perivascular edema in the second intermetatarsal vein (arrow). Coronal (C) and sagittal (D) fs T1-w postcontrast also show perivascular edema and a filling defect in the intermetatarsal veins. Note that edema follows the neurovascular plexus and is not in the plantar fat, differing from bursitis.

plantar veins, and veins were overall largest in the plantar arch location.

Perivascular edema was not identified in any case in the control group. Also, the intravascular filling defect was not identified in the post-contrast MRI sequences in the control group.

Agreement between readers

Table 6 and Figure 6 shows the agreement of vascular diameter measurements between the two readers. The highest agreements were observed for the measurements of the calibers of the plantar arch (ARCH) and posterior tibial (PT), second space intermetatarsal (MET2), and medial plantar (MP) veins. However, all vessels had an ICC greater than 0.7, indicating good agreement between the two readers. The graphs with the lowest agreement between the readers, corresponded to the diameters of the intermetatarsal veins of the first and fourth interspaces (MET1 and MET4), probably because the vessels are smaller and more curved.

Discussion

Our study showed that the lateral plantar vein was the most frequent location of PVT. An intravascular filling defect was seen in all cases using post-contrast MRI sequences. Compared to the control group, all vessels had a greater diameter in the case group, and perivascular edema was observed in all cases. Our results also suggest that a clinical history of trauma or mechanical overload (physical activities) in the foot and ankle may be one of the causal factors of this pathology.

The mechanism related to PTE and PVT is still not fully understood. It is speculated that in patients with PVT who are not anti-coagulated, there may be thrombus fragmentation due to repeated compression of the foot determined by the muscular and venous gait action. Because of this significant biomechanical compression, the pressure transmitted to the plantar venous plexus can override the blood column of the calf's deep venous system, causing thrombi in this region to spread to other parts of the body[10,11]. Thus, the correct diagnosis of deep vein thrombosis is important, and improving the diagnosis of PVT represents a crucial factor in preventing PTE.

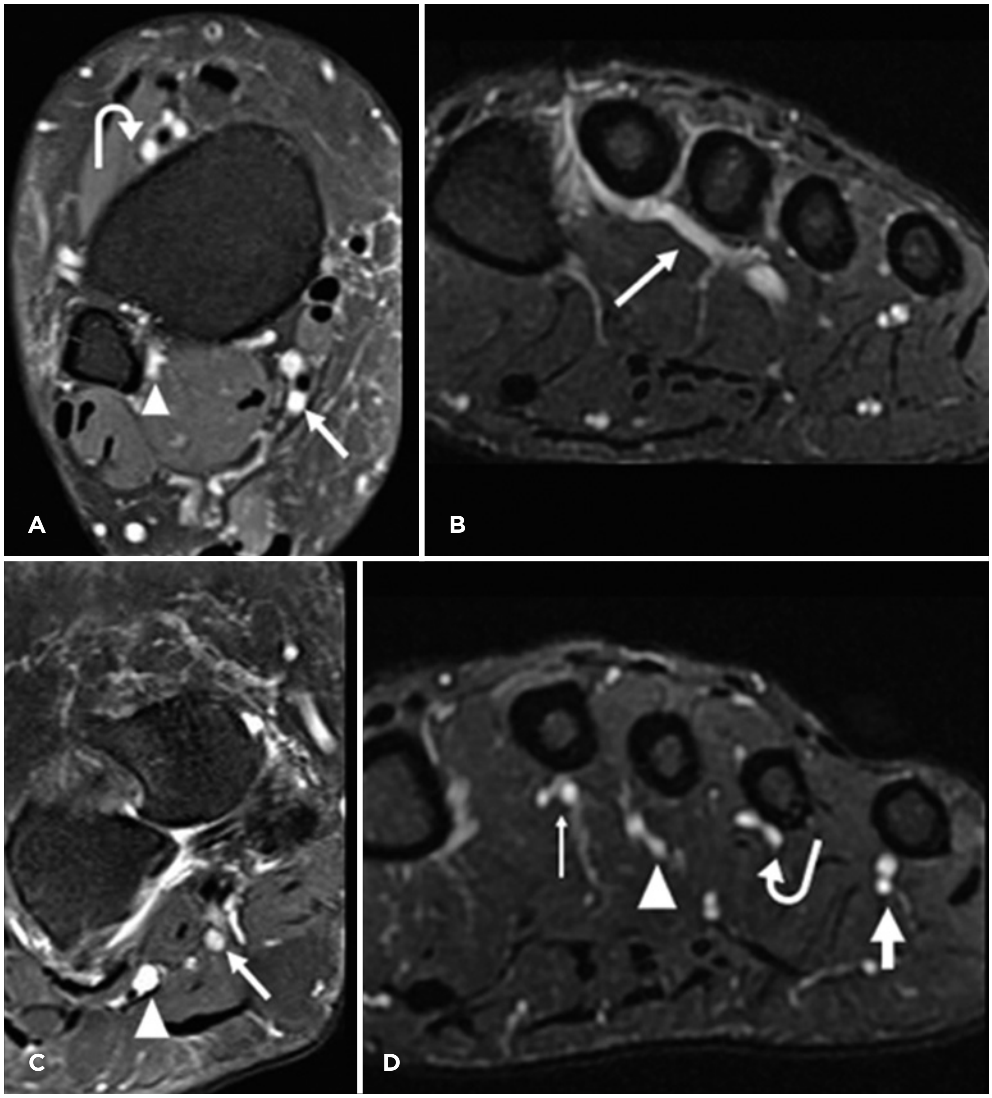

Figure 5. Measurements of vascular diameters (A to D) in a 38-year-old man presenting with heel pain for approximately three months, with progressive worsening. There were no signs of thrombosis in this study (control group). (A) Axial fs T2-w sequence in the bimalleolar plane. Caliber of the posterior tibial vein (arrow): 2.46 mm; fibular vein (arrowhead): 1.73 mm; anterior tibial vein (curved arrow): 2.48 mm. (B) Coronal fs T2-w sequence in the plane of the longest longitudinal axis of the plantar arch (arrow): 2.43 mm. (C) Coronal fs T2-w sequence at the midpoint between the bimalleolar plane and the plantar arch. Medial plantar vein caliber (arrow): 1.29 mm; lateral plantar vein (arrowhead): 2.71 mm. (D) Coronal fs T2-w sequence of the forefoot at the midpoint between the plantar arch and the transition of the intermetatarsal veins with the beginning of the interdigital veins. First space intermetatarsal vein caliber (arrow): 2.51 mm; second space intermetatarsal vein (arrowhead): 1.44 mm; third space intermetatarsal vein (curved arrow): 3.05 mm and fourth space intermetatarsal vein (larger arrow): 1.91 mm.

Table 3. Comparison between groups in numerical variables

Variable	Cases (N = 61)		Controls (N = 224)		p- value
	Mean (SD)	Median [Q1;Q3]	Mean (SD)	Median [Q1;Q3]	
Age	49.2 (15.2)	47.0 [36.8;63.0]	47.4 (14.9)	47.0 [36.0;57.2]	0.461
BMI	27.5 (5.03)	26.3 [24.5;30.0]	27.3 (5.03)	26.6 [24.0;29.8]	0.890
Time (days)	8.5 (3.9)	7.0 [6.00;10.0]			

SD: Standard deviation; Q1: Lower quartile; Q3: Upper quartile; BMI: Body mass index; Time: time in days from the onset of symptoms to the time of performing the MRI.

Inflammatory cytokines play a crucial role in the development, differentiation, and reabsorption of the thrombus, and they also act in the coordination of immune system cells[12-14]. The interaction between circulating leukocytes and injured endothelium is the major event that promotes thrombus formation, and they act together with proinflammatory cytokines such as interferon-gamma, interleukin-6, and tumor necrosis factor-alpha, increasing capillary permeability and favoring extravasation of fluid into the extravascular environment, which on MRI can be translated as perivascular edema[12]. On the other hand, leukocytes play important roles in the thrombus reabsorption process. Neutrophils and monocytes invade the thrombus to modulate collagen and fibrin degradation through the secretion of matrix metalloproteinases (MMPs) and plasminogen activators.

Table 4. Comparison between groups, categorical variables

Variable	Case (N = 61)	Control (N = 224)	p-value
Side			0.486
Right	31 (50.8%)	107 (47.8%)	
Left	30 (49.2%)	117 (52.2%)	
Sex			0.079
Female	26 (42.6%)	131 (58.5%)	
Male	35 (57.4%)	93 (41.5%)	
Comorbidities			0.178
No	22 (36.0%)	78 (47.9%)	
Yes	39 (64.0%)	85 (52.1%)	
Complaint			0.821
Pain	53 (86.9%)	175 (88.8%)	#Considering only the categories pain and pain and swelling
Pain and swelling	4 (6.5%)	20 (10.2%)	
Pain and paresthesia	0 (0%)	1 (0.5%)	
Nodule	2 (3.3%)	0 (0%)	
Paresthesia	2 (3.3%)	1 (0.5%)	
Trauma/ Recent exercise			**<0.001**
No	10 (16.4%)	77 (52.4%)	
Yes	51 (83.6%)	70 (47.6%)	

Our results showed that vein enlargement and perivascular edema were present in all plantar thrombosis cases and were not identified in the control group. Our results highlight that this finding could be used as an imaging biomarker of vascular abnormalities, and whenever it is present, the possibility of vascular thrombosis must be considered. This becomes even more important as, currently, most of the foot and ankle MRI studies are performed without the paramagnetic contrast agents, and these findings were identified in non-enhanced sequences. In cases of suspicion, the diagnosis can be confirmed with post-contrast MRI imaging, as all studied cases with thrombosis on Doppler ultrasound presented with an intravascular filling defect on MRI. Note that this is the first study to describe the non-contrast MR imaging aspects of PVT, correlating with Doppler ultrasound.

Most patients reported a history of recent physical exercise or foot trauma, suggesting that the trauma/mechanical overload could be related to endothelial wall injury activating the blood clotting cascade. This injury mechanism may also explain why the most affected was the lateral plantar vein, which has a more superficial path along the lateral segment of the plantar arch and usually bears more load in the biomechanics of gait[10]. There was no case in which the medial plantar vein was affected alone, probably due to its deeper intermuscular course in the medial segment of the plantar arch[3,15].

The caliber of vessels in cases of thrombosis was greater in all segments analyzed in relation to the examinations of controls. This difference can be explained by the presence of the thrombus inside the vessels impairing venous return,

Table 5. Vascular diameter in millimeters, comparison between groups in numerical variables

Variable Diameter	Cases (N = 61)		Controls (N = 224)		p-value
	Mean in mm (SD)	Median in mm [Q1;Q3]	Mean in mm (SD)	Median in mm [Q1;Q3]	
PT	2.78 (0.82)	2.60 [2.20;3.00]	2.57 (0.52)	2.50 [2.20;2.90]	0.332
FIB	1.94 (0.48)	1.85 [1.60;2.20]	1.75 (0.49)	1.70 [1.40;2.00]	**0.013**
AT	1.92 (0.41)	1.90 [1.60;2.10]	1.75 (0.39)	1.70 [1.50;2.00]	**0.007**
LP	3.78 (0.79)	3.80 [3.23;4.20]	3.19 (0.90)	3.10 [2.40;3.80]	**<0.001**
MP	2.45 (0.80)	2.30 [1.95;2.85]	2.10 (0.62)	2.00 [1.70;2.40]	**0.001**
ARCH	2.56 (0.93)	2.50 [2.00;3.10]	2.14 (0.72)	2.10 [1.60;2.50]	**0.001**
MET1	1.51 (0.46)	1.40 [1.15;1.90]	1.33 (0.41)	1.30 [1.00;1.50]	**0.005**
MET2	1.69 (0.70)	1.50 [1.25;2.00]	1.25 (0.37)	1.20 [1.00;1.50]	**<0.001**
MET3	1.52 (0.50)	1.40 [1.15;1.85]	1.17 (0.35)	1.10 [0.90;1.40]	**<0.001**
MET4	1.10 (0.35)	1.00 [0.90;1.20]	0.99 (0.27)	0.90 [0.80;1.10]	**0.009**

PT: Posterior tibial vein; FIB: Fibular vein; AT: Anterior tibial vein; LP: Lateral plantar vein; MP: medial plantar vein; ARCH: Plantar arch; MET 1: First space intermetatarsal vein; MET 2: Second space intermetatarsal vein; MET 3: Third space intermetatarsal vein; MET 4: Fourth space intermetatarsal vein; SD: Standard deviation.

Table 6. Agreement between readers: Measurements of position and dispersion per reader and intraclass correlation coefficient to assess agreement between readers

Vein	Reader	N	Mean	SD	Min	Median	Max	ICC	95% CI (ICC)
ARCH	1	261	2.2	0.8	0.8	2.1	6.0	0.948	0.934; 0.959
	2	261	2.2	0.8	0.2	2.0	5.5		
FIB	1	253	1.7	0.5	0.3	1.7	3.9	0.815	0.769; 0.852
	2	253	1.8	0.5	1.0	1.8	4.0		
MET1	1	263	1.3	0.4	0.3	1.2	2.9	0.707	0.642; 0.763
	2	263	1.4	0.5	0.7	1.3	5.0		
MET2	1	263	1.3	0.5	0.2	1.2	3.9	0.911	0.888; 0.929
	2	263	1.3	0.5	0.6	1.2	3.5		
MET3	1	263	1.2	0.5	0.2	1.1	3.0	0.849	0.812; 0.88
	2	263	1.2	0.4	0.5	1.1	2.8		
MET4	1	261	1.0	0.4	0.5	0.9	3.1	0.777	0.725; 0.821
	2	261	1.0	0.3	0.7	0.9	2.5		
LP	1	262	3.3	1.0	1.2	3.2	6.8	0.895	0.868; 0.917
	2	262	3.3	0.9	1.4	3.2	5.5		
MP	1	259	2.2	0.7	0.9	2.0	5.6	0.906	0.882; 0.926
	2	259	2.2	0.7	1.0	2.0	5.2		
AT	1	253	1.8	0.4	0.9	1.7	3.4	0.845	0.805; 0.877
	2	253	1.8	0.4	0.9	1.8	3.4		
PT	1	253	2.6	0.6	1.1	2.6	6.1	0.930	0.911; 0.945
	2	253	2.6	0.6	1.0	2.5	5.5		

PT: Posterior tibial vein; FIB: Fibular vein; AT: Anterior tibial vein; LP: Lateral plantar vein; MP: medial plantar vein; ARCH: Plantar arch; MET 1: First space intermetatarsal vein; MET 2: Second space intermetatarsal vein; MET 3: Third space intermetatarsal vein; MET 4: Fourth space intermetatarsal vein; SD: Standard deviation; ICC: Interclass correlation coefficient; CI: Confidence interval.

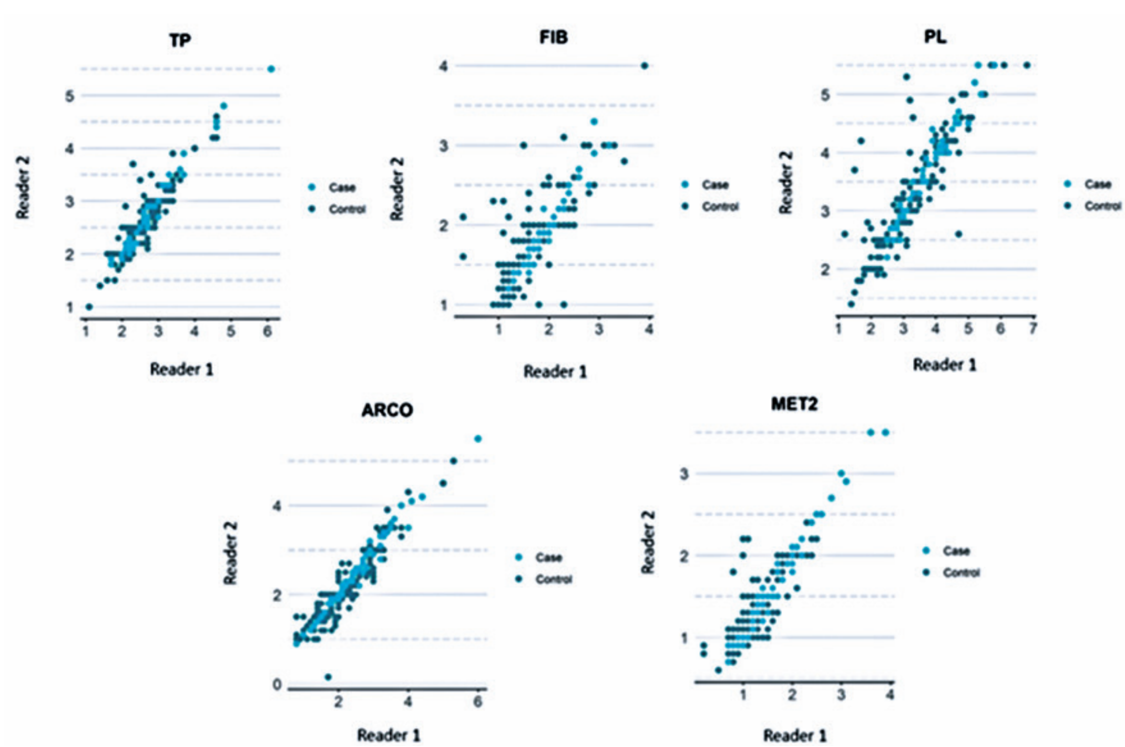

Figure 6. Scatter plots of the measurements of the two readers.
PT: Posterior tibial; FIB: Fibular; LP: Lateral plantar; ARCH: Plantar arch; MET 2: Second intermetatarsal vein.

causing vascular congestion, and increasing intravascular hydrostatic pressure and vascular caliber; this also contributes to the extravasation of fluid into the extravascular environment even in more prolonged cases of thrombosis, which also present perivascular edema[16].

In pathologies such as vasculitis, there may also be perivascular edema; however, these conditions tend to affect more vascular segments, often with bilateral involvement and a more systemic and prolonged clinical scenario[17].

Although the exact cause of PVT is unknown, it is usually associated with coagulopathies, paraneoplastic syndromes, trauma, contraceptive medication, and postoperative conditions. Recent studies report an idiopathic cause in up to 50% of cases[13,15]. It is worth mentioning that, in the absence of a defined causal factor, it is recommended to continue the diagnostic investigation in search of thrombophilia and paraneoplastic syndromes, and any respiratory symptoms that may be related to PTE should be considered[2,11,15,18].

The mean duration of symptoms in patients with thrombosis until the MRI was performed was 8.5 days, consistent with the literature[19,20]. The clinical scenario of PVT is nonspecific, usually including pain, local edema. and tenderness on palpation, and it is often confused with other more frequent causes of pain on the plantar surface of the foot, such as plantar fasciitis, musculotendinous injuries, stress fractures, plantar plate, bursitis, and neuromas. Thus, the diagnosis of PVT is usually first made through imaging exams, such as MRI or ultrasonography, and our data support that the presence of perivascular edema on foot MRI studies should raise this diagnosis.

Ultrasonography is an accessible and inexpensive method that allows the evaluation of the entire compromised vascular segment and the performance of dynamic maneuvers such as compression of the affected vascular segment. However, there are limitations to its use, which include challenges with the clinical diagnosis, the fact that the evaluation of the plantar veins is not part of the routine protocol for investigating foot pain syndrome, the difficult evaluation of vascular segments with smaller caliber, and impaired evaluation in obese patients and patients with very thick skin.

Due to its increasingly frequent use, MRI is often the first method for detecting PVT. MRI can assess all foot structures simultaneously and three-dimensionally, with good differentiation between structures, and demonstrating vascular filling defects using contrast-enhanced imaging. Furthermore, perivascular edema and an increase in vascular caliber were identified in most cases of thrombosis already in MRI sequences without contrast.

Our study had limitations, including the retrospective study design. However, we could review 61 patients with PVT, and we compared the case cohort with a control group, one of the largest cohorts to investigate this abnormality and correlate imaging and clinical data. Another limitation is the lack of longitudinal follow-up, and cases were not reevaluated after treatment and resolution of symptoms.

Conclusion

Plantar venous thrombosis is an underdiagnosed cause of acute painful foot syndrome, and due to nonspecific clinical symptoms, the diagnosis is challenging. Our study demonstrated that the most frequent location of the PVT was the lateral plantar vein. Also, it demonstrated that post-contrast MRI of PVT revealed intravascular filling defects in all cases and highlighted that vein enlargement and perivascular edema were identified in non-enhanced MRI sequences in most cases.

Additionally, it was demonstrated that one of the contributing causes to this pathology is the clinical history of trauma or mechanical overload in the foot and ankle.

Authors' contributions: Each author contributed individually and significantly to the development of this article: MDM *(https://orcid.org/0000-0001-84085037), and FOZ *(https://orcid.org/0000-0002-0167-6980), and JBG *(http://orcid.org/0000-0002 5075-5896). Conceived and planned the activities that led to the study, approved the final version; TML *(https://orcid.org/0000-0001-6653-5911) AGOF *(https://orcid.org/0000-0002-6458-3642) CASN *(https://orcid.org/0000 0002-9286-1750) MACN *(https://orcid.org/0000-0002-3350-2395) Approved the final version. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Case Report

Tibial hemimelia: a surgical approach for bone reconstruction and lengthening

Carlos Eduardo Cabral Fraga[1], Maria Eduarda Freitas Barbosa Arantes Vilela[1], Vinicius Ferreira Pires Bueno[2], Gustavo Teixeira Leão[1], Yesmin Naji Sola[3], Marcos Henrique Alves Resende[3]

1. Hospital das Clínicas da Universidade Federal de Goiás (HC-UFG), Goiâna, GO, Brazil.
2. Hospital de Urgência Otávio Lage de Siqueira (HUGOL), Goiânia, GO, Brazil.
3. Hospital de Urgência de Aparecida (HEAPA), Goiânia, GO, Brazil.

Abstract

Tibial hemimelia is a rare condition with a reported incidence of approximately one in one million live births. Although tibial hemimelia can vary its presentation, it often presents a shortened lower limb associated with deformities in the knee and ankle. The objective of this study is to present a case of tibial hemimelia and the surgical technique performed to correct the deformity and bone lengthening using a circular external fixator in several stages. A 15-year-old male patient was evaluated, presenting Jones type 3 tibial hemimelia (visible distal part, but no proximal) in the right lower limb associated with congenital clubfoot and ankle deformity. Studying and planning the patient's case was essential to classify and define the best treatment. These treatments can be flawed and often reach amputation. In the case described, several surgical approaches were performed with the objective of reconstructions and deformity correction, followed by limb lengthening, presenting excellent results.

Level of evidence IV; Therapeutic studies; Case Report.

Keywords: Hemimelia; Outcome measures; Tibia.

Introduction

Tibial hemimelia is a rare congenital pathology with an incidence of one in one million live births[1]. An important heritage correlation has been observed, with the condition linked to an autosomal recessive gene appearing unilaterally in 70% of cases[2]. Although tibial hemimelia can vary its presentation, it often presents a shortened lower limb associated with deformities in the knee and ankle. Initially, radiographs are requested for classification, indication of treatment, and prognosis. The first classification was proposed by Jones et al.[3] in 1978, which divides the deficiency into four main groups based on radiographs and bone morphology. Later, Weber[4] introduced a classification that considered the present cartilage, dividing it into seven types and 12 subtypes. Finally, in 2003, Paley[5] presented a new classification, modified in 2015, whose differentiation is directly related to treatment and prognosis[2].

Currently, the most used therapeutic approach remains amputation and prosthetics due to well-tolerated adaptation. However, recent studies and protocols have evolved to allow deformity correction and lengthening, preserving the limb, especially in mild presentations. In these cases, it is possible to use circular external fixators on the femur, tibia, and foot for limb stabilization and lengthening. In other cases, it is possible to apply Brown's procedure[6] to centralize the fibula between the femoral condyles and talus using gradual distraction for fibula centralization.

Study performed at the Hospital das Clínicas da Universidade Federal de Goiás (HC-UFG) Goiâna, GO, Brazil.

Correspondence: Maria Eduarda Freitas Barbosa Arantes Vilela. Rua 235 QD. 68 Lote Área, Nº 285, s/nº - Setor Leste Universitário, 74605-050, Goiânia, GO, Brasil. **Email:** dudavilela97@gmail.com. **Conflicts of interest**: none. **Source of funding:** none. **Date received:** June 22, 2024. **Date accepted:** August 20, 2024. **Online:** August 30, 2024.

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The objective of this study is to present a rare case of tibial hemimelia, treatment with bone reconstruction using a circular external fixator in several stages, and to systematize knowledge and therapeutic possibilities.

Case presentation and surgical technique

A male patient presented with deformity in the right lower limb at birth and was diagnosed with a cavo-adducto-varus deformity at three days of life and started clinical treatment with serial cast immobilization for two months without satisfactory results. He was diagnosed with tibial hemimelia at six months; however, the patient was followed up in another service where surgical treatment was performed with tibia and distal fibula resection, talar dome associated with plantar fasciotomy, maintaining irregular follow-up.

At 16, he resumed follow-up with the persistence of congenital malformation, including cavo-adducto-varus, as well as deformity and joint instability in the knee and ankle. Additionally, there was a shortening of approximately 9 cm in the right lower limb, affecting both the thigh and leg (Figure 1).

Surgical treatment was planned in a single time, with tibiotalar synostosis and limb lengthening to correct dysmetria, and outpatient follow-up with lengthening presenting satisfactory bone regeneration, with programming for external fixator including the knee due to instability and continuity of treatment.

Surgical technique

The patient was operated on in dorsal decubitus, initially using the tourniquet. The first approach was anterolateral access to the ankle, with a slightly curved incision starting from 5 cm proximal to the lateral malleolus to 2 cm medial to the fifth metatarsal. Then, dissection was performed by layers until bone exposure of the tibia and fibula. A 4 cm resection of the distal portion of the tibia and fibula was performed, repositioning the right foot to a plantigrade shape and fixing it with three Kirschner wires. Once the tourniquet was removed, a new anteromedial incision in the proximal third of the tibia was performed for osteotomy in this same segment, following the Italian technique with multiple perforations with drill and irrigation with saline, completed with the use of an osteotome. After positioning a circular external fixator encompassing the hindfoot and tibial block to increase arthrodesis stability, these procedures were performed in July 2021 (Figure 2).

After the tenth postoperative day, the lengthening started at 0.75 mm/day (0.25 mm every eight hours) for one week, evolving to 1 mm/day (0.25 mm every six hours) until the end of the first month. In the second month, change the lengthening rhythm to 0.25 mm/day four times daily. Initially, the patient was resistant to the treatment using a circular fixator; however, he progressed slowly at the beginning of the third month, with partial weight-bearing using crutches. The radiographic follow-up showed distraction osteogenic with satisfactory bone regeneration, and the replacement of the fixator was scheduled to start the second stage of lengthening in December 2022.

In June 2023, the patient still resisted the total discharge of body weight on the limb, walking with compensation in footwear and crutches-no pain complaints, with strength deficit of the extensor mechanism. A new circular external assembly was then performed to finalize the lengthening, encompassing the knee in this second moment due to cruciate ligament agenesis. In addition, a new osteotomy of the proximal tibia was performed to allow distraction to continue (Figure 3).

After six months of outpatient follow-up, maintaining partial weight-bearing using crutches and lengthening with a distraction of 0.25 mm/day, it was reopened to remove the distal assembly in the femur and distal reassembly (Figure 4) in the hindfoot, allowing the patient to load and reinforce the formed bone regenerate (Figure 5). At this moment, the patient presented a stable right knee joint for daily activities,

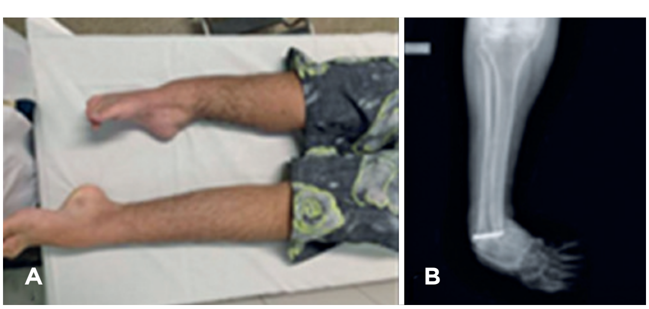

Figure 1. (A) Clinical aspect of deformity and shortening of the right lower limb (shortening of approximately 9 cm, with the right foot in cavo-adducto-varus) (B) anteroposterior radiography.

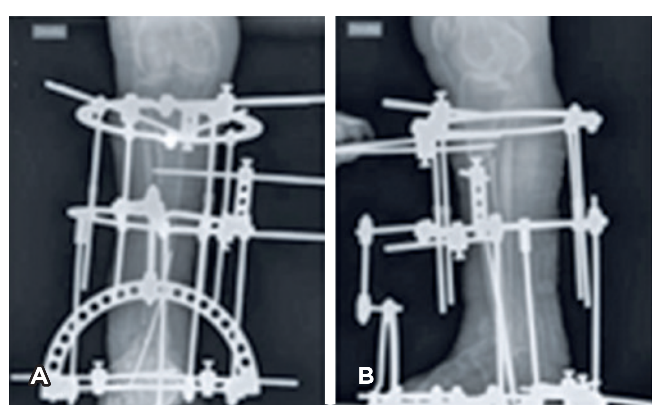

Figure 2. Anteroposterior (A) and profile (B) radiographs of the right lower limb after the first single-time approach of attempting talar tibial arthrodesis, fixed with Kirschner wire and assembly of a circular external fixator encompassing the tibial block and foot.

with a good range of motion, without pain complaints, with the plantigrade foot, allowing gait, however, with the presence of residual cavus.

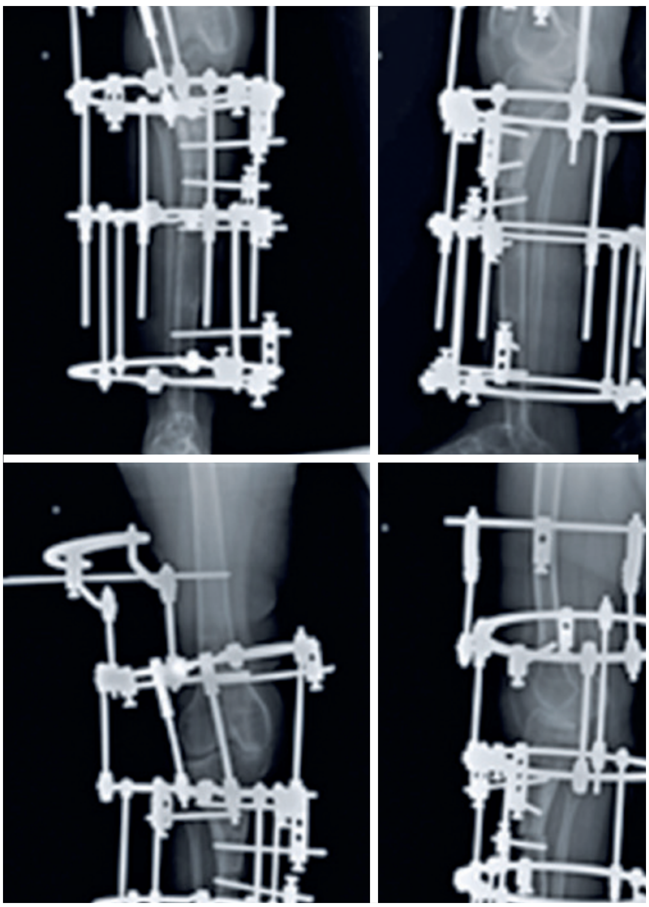

Figure 3. Anteroposterior and profile radiographs of the leg and knee, with the assembly of circular external fixator, including knee and ankle for bone lengthening, with osteotomy in the proximal tibia.

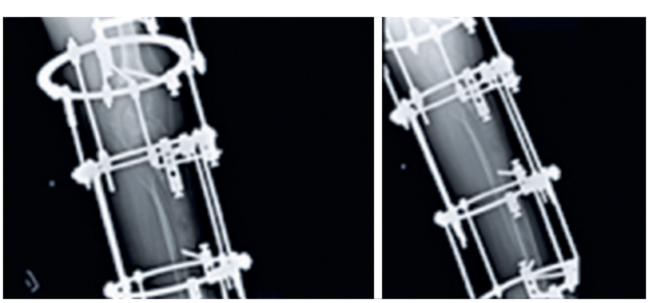

Figure 4. Internal and external oblique radiographs of the knee and right leg show bone regeneration in the formation process in the proximal third of the tibia after outpatient follow-up.

Discussion

The first case of tibial hemimelia was described in 1841; by 1941, there were already 79 documented cases[7]. Prenatal diagnosis can be made from the 16th week of gestation by ultrasound, and the genetic inheritance can be autosomal dominant or recessive.

There are different classifications for tibial hemimelia; Jones[3] is one of the most popular, using simple radiographs to differentiate into four main groups and 11 subtypes[1]. Type I has total distal tibia aplasia, subdivided into Ia, with distal hypoplasia of the femur, and Ib, with normal ossification of the epiphysis of the femur. Type II with ossified proximal tibia and distal tibial agenesis. Type III is the ossified distal tibia, and type IV is the shortened tibia with diastasis in the distal region between the tibia and fibula, as in the case above. The Paley classification[5], published in 2003 and modified in 2015[2], relates treatment to disease prognosis. The pathology is divided into five types and 11 subtypes, progressively evolving according to the involvement[2] (Figure 6).

Type 1: Hypoplastic tibia: valgus proximal tibial, relative growth of proximal fibula, tibial plateau present and normal**.**

Type 2: Proximal and distal tibial epiphysis present with dysplastic ankle

2A: Well-formed distal tibial physis; dysplastic tibial plateau; relative growth of proximal fibula.

2B: Delta tibia, proximal and distal growth plates connected through the epiphysis, ankle joint dysplasia; relative growth of proximal fibula.

2C: Delayed ossification (cartilaginous enlargement) of part, or all, of the tibia; dysplastic ankle joint; absence of tibial distal physis, relative growth of proximal fibula.

Type 3: Proximal tibia and knee joint present, medial malleolus present, distal tibial plateau absent, tibio-fibular diastasis.

3A: Lateral malleolus present, varus diaphyseal tibia, distal fibula with foot internally rotated around the tibia, talus can

Figure 5. Clinical image after removal of the knee assembly, with a new distal assembly, encompassing the ankle to perform full weight-bearing on the right lower limb using crutches.

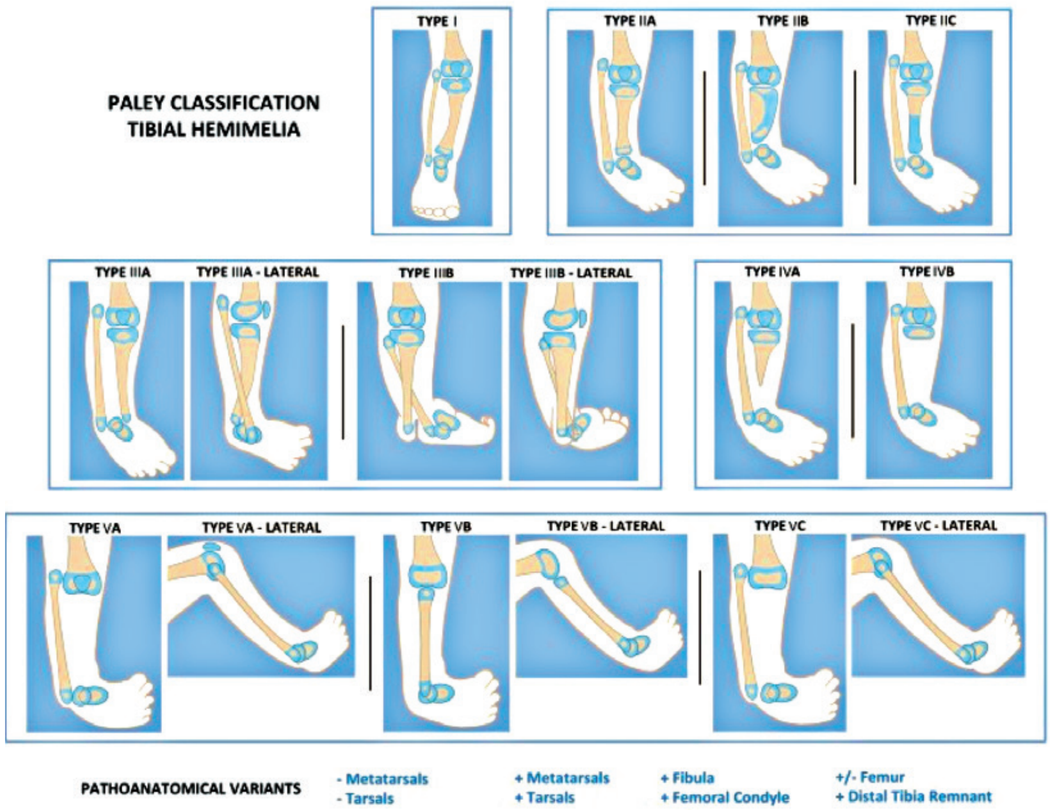

Figure 6. Paley Classification.
Source: Paley Foundation.

be positioned between the tibia and fibula due to absence of tibial plateau, relative growth of proximal fibula.

3B: Same as 3A with skin cleft separating the tibia and fibula, foot always follows the fibula.

Type 4: Distal tibial aplasia.

4A: Knee joint present, complete absence of tibia from diaphysis, pointed bone end often covered by skin pouch, relative growth of proximal fibula.

4B: Proximal tibial epiphysis present, knee joint present, relative growth of proximal fibula.

Type 5: Complete tibial aplasia.

5A: Complete absence of tibia, patella present; flexion contracture of knee, equinus-varus contracture of dislocated foot and ankle.

5B: Complete absence of tibia, no patella; flexion contracture of knee, auto-centered fibula, quadriceps present, knee capsule present.

5C: Complete absence of tibia, no patella; flexion contracture of knee, dislocated fibula, quadriceps present, no knee capsule.

In addition to the changes already described, they may present joint instability in the ankle and knee, malformations, and even muscular agenesis of the quadriceps and patella, cruciate ligaments, and dysplastic or absent collaterals.

The treatment of tibial hemimelia is controversial, with amputation being the gold standard, especially in Jones' subtypes Ia and Ib, arguing for faster adaptation, especially in younger people. However, treatment acceptance varies across cultures and bone reconstruction has become more common. Recent studies show that satisfaction and quality of life tend to be better with reconstruction, but complications such as contractures, instability, and infections occur.

The choice of reconstruction method depends on the classification, experience of the surgeon, and quality of soft and joint parts of the limb. In 1965, Brown[6] proposed a surgical technique for centralizing the fibula, with the purpose of transforming it into a functional tibia combined with the Ilizarov technique for gradual correction of dysmetria and soft tissue distraction. In 2015, Paley[2] proposed an update to the classification, allowing new surgical approaches associated with existing techniques, including correction of foot deformity, femoral osteotomy, and patelloplasty when necessary, allowing improvement of soft tissues. However, the benefits and applicability of the treatment remain uncertain, especially regarding the persistence of contractures, the prolonged duration of treatment, and associated complications.

It is important to reinforce the decision between early amputation or correction. Studies state that patients who have been submitted to serial reconstruction procedures with prolonged use of the fixator experience improved self-esteem after correcting the deformity[7]. Subjective aspects such as decreased pain and a higher degree of satisfaction after length correction were also observed, presenting better psychological results. In the case presented, the previous approach and the patient's desire was the surgical approach for correction and stabilization of the ankle joint and bone reconstruction to correct deformities with a circular external fixator. At the end of the treatment, the patient presented an excellent result from the functional point of view, the right knee, despite the cruciate ligament agenesis, underwent good stability to demand daily activities, in addition to a wide range of motion, without evolving with residual knee flexion, an evolution described in some studies after the use of an external fixator encompassing this joint. A 7 cm length was obtained in the right tibia, with persistence of 2 cm of final discrepancy in the lower limbs. Regarding the foot, corrected until reaching the plantigrade position, allowing the discharge of total weight on the limb during the gait, using crutches, despite persisting with residual cavus, which will be later programmed and corrected. Finally, the patient preserved proprioception in the foot, which allowed greater stability during ambulation.

Final Considerations

Given the rarity and wide variety of presentations of tibial hemimelia, understanding its treatment becomes complex and challenging. Before choosing the best therapeutic approach, it is important to identify and classify the type of hemimelia, determining the prognosis and the best therapeutic options. There are several reconstructive techniques, but many end up failing and require amputation. In the case described, the patient had multiple approaches, using a circular external fixator for a long period, obtaining an excellent lengthening result, providing a plantigrade foot with satisfactory sensitivity and proprioception, in addition to allowing the functional quality of the limb.

Authors' contributions: Each author contributed individually and significantly to the development of this article: CECF *(https://orcid.org/0000-0002-3832-7397), and MEFBAV *(https://orcid.org/0000-0002-3003-2631), and VFPB *(https://orcid.org/0009-0003-4421-9549), and GTL *(https://orcid.org/0000-0003-3489-9192) Conceived and planned the activity that led to the study, wrote the article, participated in the review process; YNS *(https://orcid.org/0000-0003-0719-3223), and MHAR *(https://orcid.org/0009-0007-6711-0510) Data collection, bibliographic review; formatting of the article, bibliographic review; All authors read and approved the final manuscript.*ORCID (Open Researcher and Contributor ID) iD.

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Case Report

Bizarre parosteal osteochondromatous proliferative lesion of the hallux

Zuko Siyo[1], Nikiforos Pandelis Saragas[1], Paulo Norberto Faria Ferrao[1]

1. Orthopaedic Foot and Ankle Unit, Netcare Linksfield Hospital, Johannesburg, South Africa.

Abstract

Foot tumors are a rare occurrence, which can make diagnosis and management difficult. Certain benign tumors can be locally aggressive, with a rapid progression resembling a malignancy. We present a case of bizarre parosteal chondromatous proliferative (BPOP) lesion, also known as Nora lesion, arising from the sesamoid. This is a benign lesion with overlapping clinical and radiological features of a malignant neoplasm. Highlighting classic BPOP characteristics is crucial in avoiding potentially incorrect management and resulting morbidity.

Levels of evidence IV; Therapeutic studies; Case Report.

Keywords: Foot tumor; Hallux.

Introduction

Primary bone tumors account for 2% to 4% of all neoplasms. With regard to soft tissue tumors, 8% of benign tumors and 5% of malignant tumors occur in the foot and ankle(1).

Common benign soft tissue tumors found in the foot include plantar fibromatosis, ganglion cyst, giant cell tumor of tendon sheath, pigmented villonodular synovitis, and lipoma. More prevalent benign osseous lesions include osteoid osteoma, enchondroma, aneurysmal bone cyst, and chondroblastoma(1).

The possibility of any lesion being malignant should always be considered, as it has been shown that pain, lesion size, and symptom duration are not reliable in differentiating benign and malignant lesions(2). Although malignant bone tumors are rare in the foot, osteosarcoma, Ewing sarcoma, and chondrosarcoma do occur(1). Malignant melanoma is also fairly common in the foot, with potential life-threatening consequences if left untreated(3).

The low incidence of large soft tissue tumors in the foot makes the diagnosis and management of these lesions challenging. We present a rare case of bizarre parosteal osteochondromatous proliferation (BPOP) in the foot. This case study aid the reader in making this difficult diagnosis and managing the lesion appropriately. Informed consent was obtained from patient.

Case report

Clinical history

We present the case of a 56-year-old female patient who presented with a progressively slow growing mass under the left hallux. She reported a previous soft tissue injury to this left hallux three years prior. Wound healed uneventfully with local dressings. Eighteen months ago, she noticed a mass growing under the left hallux. The mass increased significantly in size over time, causing difficulties in wearing and walking in closed shoes. She consulted her local podiatrist, who recommended having the mass assessed by a surgeon. She reported no night pain.

Examination

Examination revealed a generally well Caucasian female. She walked on the lateral border of the left foot with supination of the forefoot to avoid pressure on the mass. Clinically, she had a 3 cm x 5 cm mass under the left first metatarsal head. The mass had a firm rubber-like consistency and was not adherent to the overlying soft tissue. There were no skin changes or increased local temperature. There was no tenderness on palpation. Sensation was altered over the plantar aspect of the hallux. Range of motion was limited in

Study performed at the Netcare Linksfield Hospital, Johannesburg, South Africa.

Correspondence: Paulo Noberto Faria Ferrao. Netcare Linksfield Clinic, 24 12th Avenue, Linksfield West, Johannesburg, South Africa. **E-mail:** paulo@cybersmart.co.za. **Conflicts of interest:** None. **Source of funding:** None. **Date received:** April 22, 2024. **Date accepted:** June 25, 2024. **Online:** August 30, 2024.

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the metatarsophalangeal joint (MTPJ) due to impingement by the mass.

Special investigations

Radiographs of the foot showed a soft tissue lesion containing calcifications below the first metatarsal head (abutting the medial sesamoid), with no bony changes (Figure 1).

Magnetic resonance imaging (MRI) of the hallux showed a 56 mm x 27 mm x 30 mm heterogeneous septate mass with calcifications. Rim was calcified and enhanced with contrast (Figure 2). The mass enveloped the medial sesamoid and communicated with the MTPJ, displacing the flexor hallucis longus (FHL) medially. Differential diagnosis on MRI was tenosynovial giant cell tumor (calcification is rare in this type of tumor) and tumoral calcinosis (rare in the foot).

Computed tomography (CT) scan confirmed calcification within the mass. The mass enveloped the medial sesamoid but did not breach the cortex (Figure 3).

Management

Patient was consented for an excisional biopsy of the soft tissue mass. An L-shaped incision was made in the flexor crease of the first MTPJ, extending along the medial border of the lesion (Figure 4). Lesion was found to be well encapsulated and excised en bloc, while protecting the sensory nerves (Figure 5). The FHL was intact and not adherent to the lesion (Figure 6). The lesion seemed to originate from the medial sesamoid. The mass was sent for histology. Wound was closed in layers. Patient was mobilized in a heel weight-bearing wedge shoe. Stitches were removed at three weeks, by which time the wound had healed well. Patient was placed in supportive shoes at four weeks. At the 12-week follow-up, patient was back to normal shoe wearing and performing normal daily activities without any discomfort (Figure 7).

Histopathology

Histology reported a 49 mm x 35 mm x 20 mm specimen, showing a well-circumscribed, multilobulated lesion (Figure 8). Within the lobules, there was irregular and immature cartilage with enlarged bizarre binucleated chondrocytes. Chondro-osteoid tissue stained characteristically blue using hematoxylin and eosin stain (H&E), with enlarged bizarre binucleated chondrocytes. There was spindle cell proliferation between the bone trabeculae (Figure 9). Diagnosis of BPOP was reached. Specimen was reported to have clear margins.

Discussion

Bizarre parosteal osteochondromatous proliferation is a rare benign, non-infiltrative bone surface lesion. It was originally described by Nora et al.[4] in 1983, hence the term Nora lesion. This type of lesion is mostly found in tubular bones of the hands and feet, with a 59% to 27% distribution respectively[4]. Infrequently, they occur in long bones and the skull. Atypical presentations have been reported in the calcaneus and talus[5]. These lesions commonly occur in middle-aged patients, but have been reported in patients ranging from 12 to 81 years of age, with no specific gender predilection[6]. Its

Figure 1. Antero-posterior and lateral radiographs showing the soft tissue mass with calcifications below the first metatarsal head.

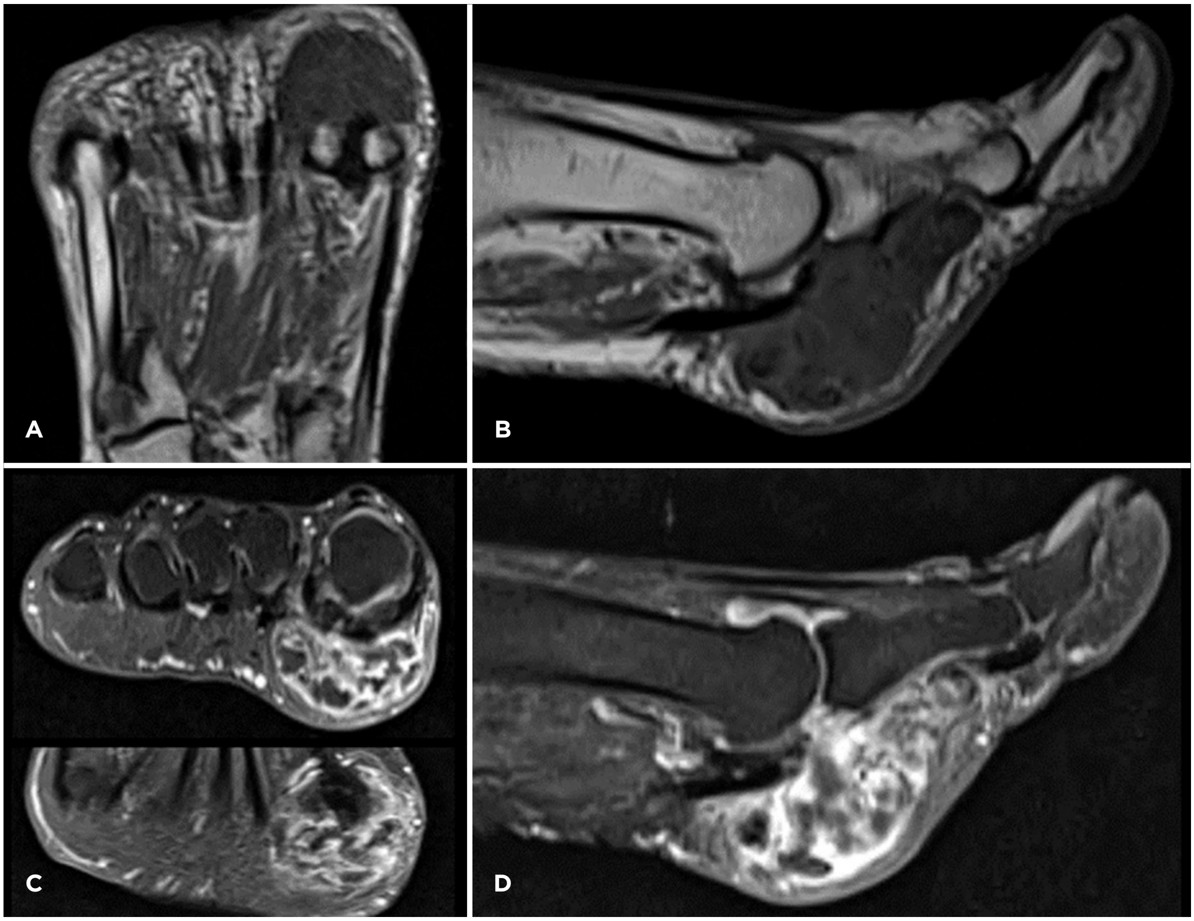

Figure 2. (A) T1-weighted axial MRI image showing a mass with uniformly low signal. (B) T1-weighted sagittal MRI image showing a mass with uniformly low signal. (C) Fat-saturation with contrast axial MRI image showing increased signal with calcification and rim enhancement. (D) Fat-saturation with contrast sagittal MRI image showing increased signal with calcification and rim enhancement.

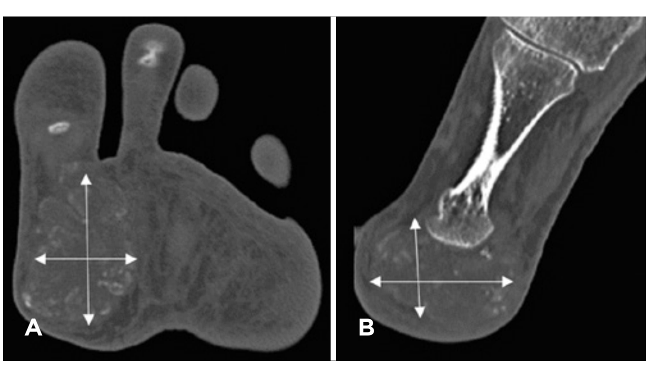

Figure 3. (A) CT scan axial image showing calcification within the lesion. (B) CT scan sagittal image showing no cortical breach of the metatarsal head by the lesion.

Figure 4. Lesion was approached using an L-shaped incision in the flexor crease of the first MTPJ extending along the medial border of the lesion.

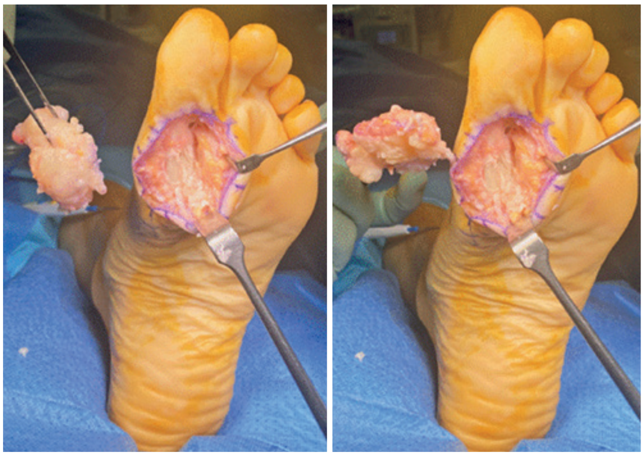

Figure 5. Lesion was found to be well encapsulated, being excised en bloc.

Figure 6. The FHL was intact and not adherent to the lesion.

Figure 7. Wound had healed well in six weeks, with no painful scaring.

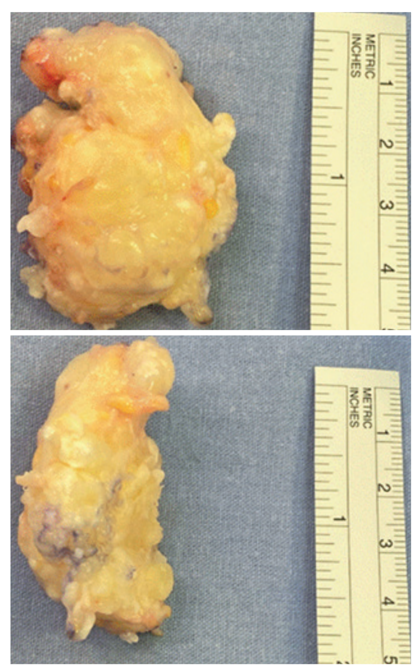

Figure 8. Macroscopic image showing a well-circumscribed, multilobulated lesion.

features resemble a malignancy, such as rapid growth, high rate of recurrence, and an atypical histological appearance. No case of malignant transformation has been reported, but these lesions can become aggressive and locally invasive.

Bizarre parosteal osteochondromatous proliferation can either be a slow or rapidly growing lesion which is inherently not painful. Overlying soft tissue is generally not affected by the lesion. As presented in our case, patient had no tenderness

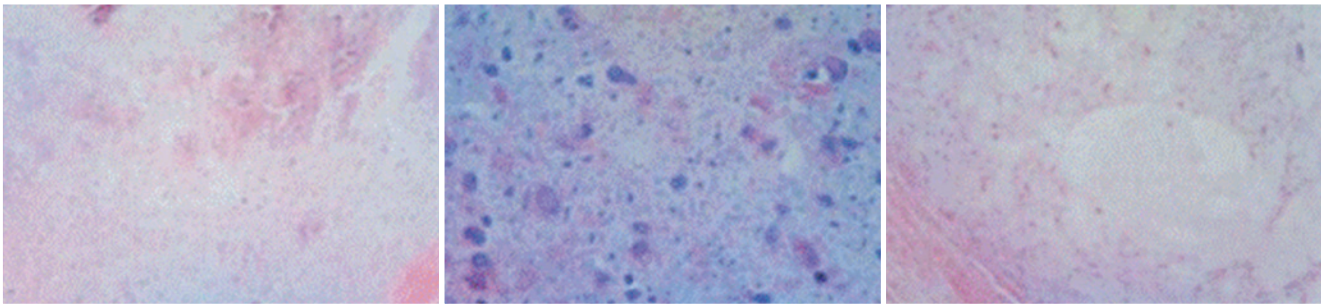

Figure 9. Histological images showing a chondro-osteoid tissue which stained characteristically blue using hematoxylin and eosin stain. There is a spindle cell proliferation between the bone trabeculae and enlarged bizarre binucleated chondrocytes.

over the lesion but struggled with activity and shoe-wearing problems related to the increasing lesion size. There is no specific known etiology, but previous traumatic periosteal damage has been suggested to be a predisposing factor, as seen by histological similarities to callus and subungual exostosis[4]. Edoardo et al.[7] suggested that these lesions have a multifactorial pathogenesis, with trauma being a high-risk factor[7]. Our patient reported a significant soft tissue injury to her left hallux prior to developing the lesion. Nilsson et al.[8] detected a translocation between chromosome 21 and 32 t (q32;21) in five cases, and also found balanced translocation between chromosome 1 and 17 t (1;17) in four of five cases, indicating a genetic predisposition[8]. Similar findings of balanced translocation of chromosomes t (1:17) and q (32;21) in BPOP cases have been identified by other authors[9].

Radiological features of BPOP have close resemblance to those of bone reactive lesions and benign neoplasms such as florid reactive periostitis, myositis ossificans, osteochondroma, and periosteal chondroma[10]. Malignant lesions like parosteal osteosarcoma and chondrosarcoma are part of the differential diagnosis in cases of rapid growing BPOP lesions. Plain radiographs show a classic well-circumscribed, mineralized lesion that abuts the cortex of the neighboring bone. This radiographic feature differentiates a BPOP lesion from myositis ossificans, which has characteristic islands of calcification not arising from the adjacent bone. The CT scan of BPOP lesions clearly demonstrates the absence of medullary communication between the adjacent bone and the lesion, which distinguishes it from an osteochondroma. Lack of cortical erosion and periosteal reaction differentiates this lesion from malignant tumors[11]. Current case's CT scan showed the lesion originating from the medial sesamoid, but not compromising the cortex. Typical BPOP MRI findings are that of uniformly low signal in T1-weighted images, while on T2-weighted and STIR images the lesion has intermediate signal in the center, with high signal intensity around the periphery[6,11].

Histological confirmation must always be attained when managing tumors. Microscopic features of BPOP lesions are bizarre cartilage with hypercellular large binucleated chondrocytes blending with woven bony trabeculae on a fibrous background comprised of reactive-looking spindle cells. Thus, the lesion is a mixture of cartilaginous, osseus, and fibrous tissue. The research conducted by Cocks et al.[12] on the histological variability of 16 BPOP cases reported a characteristic finding of "blue bone" in all specimens. "Blue bone" has been defined as an unusual mineralized cartilaginous matrix. Presence of "blue bone" and significant fibrous tissue is highly suggestive of a BPOP lesion[12]. There is no presence of cellular atypia, which would be suggestive of malignancy[4].

Such BPOP lesions are best managed by performing a wide local excision with clear margins as definitive treatment. It is important to get clear margins, as these lesions have a local recurrence rate of 37.4%[7]. In a case series of 22 Nora lesion cases by Berber et al.[13], 21 patients had surgical excision and one patient had amputation of the toe due to the size and local infiltration of the lesion. Recurrence occurred in six patients (27.3%), with a mean time to recurrence of 49 months. Two of eight patients with clear margins on histology had recurrence (25%), compared to 4 of 14 patients with marginal or incomplete resection (28.6%)[13]. There is no mention in the available literature regarding the possible use of radiation therapy to try to prevent recurrence. There has been no recurrence in our case at one-year follow-up after management with local excision.

Atypical BPOP lesions have been reported. Lesions are considered as being atypical according to either their location or radiological appearance. Atypical locations include facial bones, spine, clavicle, radius, fibula, calcaneus, talus, and sesamoids. Atypical imaging features are erosion of the cortex by the lesion and extension into the medullary canal. These atypical BPOP lesions are difficult to differentiate from malignant tumors without histological confirmation[7,14].

In conclusion, BPOP is a rare benign lesion that mimics both benign and malignant processes. It can be differentiated from other tumors by its typical radiological and histological characteristics. This atypical presentation of a BPOP lesion arising from the sesamoid highlights the need for a high index of suspicion and good clinical acumen when dealing with this condition so as to avoid inappropriate and destructive management.

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Case Report

Timely tibiotalar fusion after utilization of Masquelet technique guided by in-hospital 3D printing

Ahmed Nageeb Mahmoud[1,2], John Alexander Holbert[1], Benjamin Richards Wagner[1], Daniel Scott Horwitz[1]

1. Department of Orthopedic Surgery, Geisinger Medical Center, Danville, PA, USA.
2. Department of Orthopedic Surgery, Ain Shams University Faculty of Medicine, Cairo, Egypt.

Abstract

The following report describes a case of a 24-year-old female who presented with a traumatic open trimalleolar ankle fracture with severe distal tibial bone loss. She was submitted to a staged acute Masquelet technique, where the in-hospital 3D printing was utilized to guide the shaping and sizing of the antibiotic cement spacer and, subsequently, the bone allograft utilized two months later during tibiotalar fusion. Adequate bony consolidation was achieved at the 7-week follow-up, and the patient was able to bear weight at 12 weeks fully.

Level of Evidence V; Therapeutic studies; Case Report.

Keywords: Ankle; Arthrodesis; Printing, three-dimensional.

Introduction

The induced membrane technique, the Masquelet technique, typically comprises two-stage surgery using temporary antibiotic-loaded bone cement (Polymethyl methacrylate - PMMA) as a spacer to promote pseudo membrane formation in the surgical bed that enhances bone healing[(1)]. Since its introduction, the Masquelet technique has been utilized in the management of multiple orthopedic conditions, including reconstruction of traumatic or pathological critical bone defects[(1-5)], among other indications, with excellent results.

Three-dimensional printing (3DP) is a rapidly evolving technology increasingly gaining popularity in several aspects of orthopedic surgery. Given its widespread utilization, efforts are made to improve the cost efficiency of 3DP in the health system. Several health institutions have integrated the radiology-based, in-hospital 3DP[(6)].

The benefit of combining 3DP applications with the Masquelet technique for surgical planning or manufacturing of implants and bone fillers has been reported to manage infections and traumatic bone defects[(7)]. In this case study, we report a case of traumatic distal tibial bone loss that was managed successfully with 3DP-assisted, acute Masquelet technique[(3)] followed by tibiotalar fusion. Our aim is to add to the literature about the utility of in-hospital 3DP in acute trauma management and describe the effect of the Masquelet technique in achieving a timely bone consolidation after limb salvage arthrodesis. The patient signed the informed consent form and agreed to utilize the de-identified data for research purposes. To our knowledge, a similar case and surgical technique has not been published before.

Case description

An otherwise healthy 24-year-old female with a body mass index (BMI) of 32 presented to the emergency room of our level-1 trauma center with an open Gustilo grade III B, left Trimalleolar ankle fracture associated with a large anterior distal tibial bone loss and secondary ankle subluxation (Figure 1A-C), after a motor vehicle accident. After ensuring neurovascular integrity, emergency wound coverage, closed reduction, and splinting were performed (Figure 1D, E). After clearing the patient for surgery, the patient was taken for

Study performed at the Geisinger Medical Center, Danville, PA, USA.

Correspondence: Ahmed Nageeb Mahmoud. Geisinger Musculoskeletal Institute. 100 N Academy Ave Danville, PA 17821. **Email:** amahmoud@geisinger.edu.
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wound debridement and irrigation, an external fixator was placed, and an antibiotic bead pouch was applied (Figure 1F-H). Intraoperative findings (Figure 1A, H) and postoperative computed tomography (CT) scan (Figure 1I, J) showed a large triangular bone defect in the distal anterior tibia, representing approximately 40% of the articular surface. The patient returned to the OR for a second-look debridement and exchange of antibiotic delivery system.

Given the large area of articular bone, cartilage loss, and the wound condition, the decision was to continue using external fixation with the utilization of acute Masquelet technique with plans for a delayed ankle fusion after proper soft tissue healing. The consulting plastic surgeon decided on a free lateral femoral fasciocutaneous flap with a skin graft for coverage. To create a bone graft that would fit the bone defect during the fusion surgery, the surgery team decided that the antibiotic delivery system should precisely fit the bone defect to preserve the space for later fusion and, more importantly, create a similarly shaped and sized bone graft fragment during the planned fusion surgery. After performing a 3D reconstruction CT scan (Figure 2A), the in-hospital, radiology-based 3DP service was used to create a custom-made bone mold of the patient's distal tibia (Figure 2 B-D).

Two days later, the planned surgery was performed. The bone models were used intraoperatively inserted in sterile ultrasound bags (Figure 2E), and gentamicin and vancomycin-loaded bone cement (PALACOS® fast R+G) were utilized to create a cement spacer fragment that matched the size of the tibial bone defect (Figure 2 E, F). After wound re-debridement, irrigation, and adjustment of the external fixator, the cement spacer was fitted into the bone defect (Figure 2F-H). On the next day, the planned plastic surgery was performed. The patient was discharged after 14 days. After six weeks, soft tissue coverage was confirmed, and definitive fusion was planned.

The decision was to utilize the anterolateral ankle approach for performing the ankle fusion surgery[8], lateral to the edge of the flap, based on the native soft tissue that was

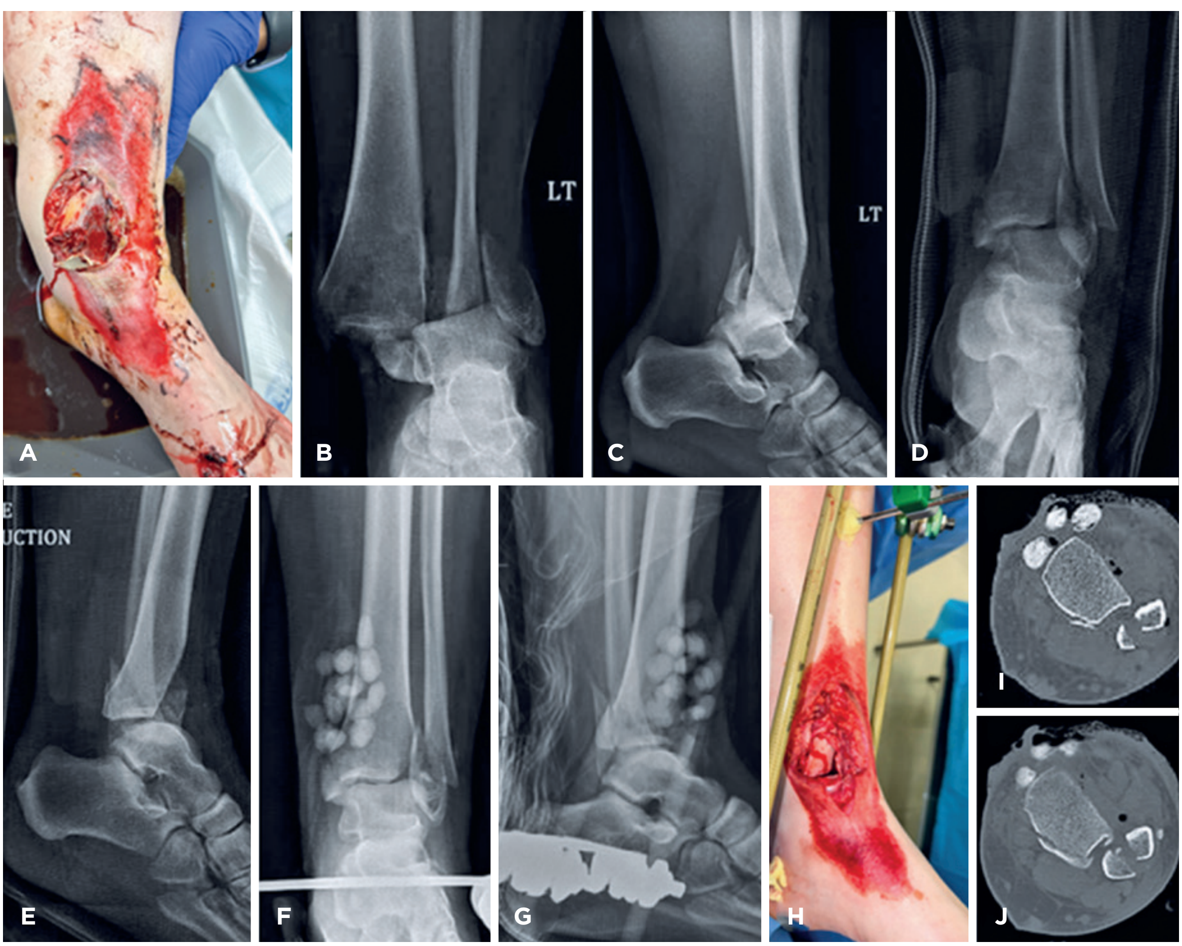

Figure 1. A) Clinical photo, and B, C) Plain radiographs of the limb upon presentation. D, E) Plain radiographs after closed reduction and splinting. F, G) Plain radiographs after debridement, antibiotic beads insertion, and placement of external fixator. H) Clinical photo after application of external fixator. I, J) Postoperative axial CT scan cuts showing anterior tibial bone loss.

not disturbed by the previous flap (Figure 3). After removal of the external fixator, incision and exposure of the bony articular surface were performed (Figure 3B-D), and the old cement spacer was removed and preserved in a sterile saline for reference. The ankle was then distracted using a laminar spreader, and the remaining articular surface was carefully prepared for arthrodesis by removing the remaining cartilage and subchondral bone, ensuring no damage to the fibrous pseudo membrane (Figure 3C). A calcaneal cross-section allograft was then shaped to the size of the extracted cement spacer (Figure 3E-H) and mixed with 10CC demineralized bone fiber and bone marrow aspirate concentrate. The ankle joint was irrigated, then compressed and fixed with preliminary pins in the appropriate, aligned position, and the custom allograft wedge was placed in the anterior defect. (Figure 3I). An anterolateral ankle fusion locking plate was utilized to stabilize the bone graft and fix the tibia to the talus (Figure 3J, K, and Figure 4A-C). The wound was then closed without a drain.

Postoperatively, the patient was instructed to wear a cam boot and maintain a non-weight-bearing status until the achievement of bone fusion, and the patient had biweekly follow-ups. At the 7-week follow-up radiographs, bony consolidation was observed (Figure 4D, E), and the patient began 20% weight bearing using an assistive device. Progressive radiological fusion was observed at 12-week radiographs, and the patient was allowed to advance weight-bearing in a cam boot with gradual progression to full weight-bearing. At the last follow-up, 28 weeks postoperatively (Figure 4L-N), the patient was pain-free, fully weight-bearing without assistive devices, and was cleared to return to work.

Discussion

This case study highlights the efficacy of the Masquelet technique in the achievement of timely, uneventful ankle fusion after reconstruction of severe distal tibial bone loss. The utilization of in-hospital 3DP allowed for the creation of a properly sized cement spacer and, more importantly, the allograft that fitted the bone defect during the fusion surgery.

Acute Masquelet technique[3] is a recent term that describes an existing procedure. It utilizes the induced membrane technique as a primary treatment of bone defects in the acute setting of open fractures[3-5]. In this technique, the bone defect secondary to trauma is filled with PMMA to create a pseudo membrane that can support and promote the bone

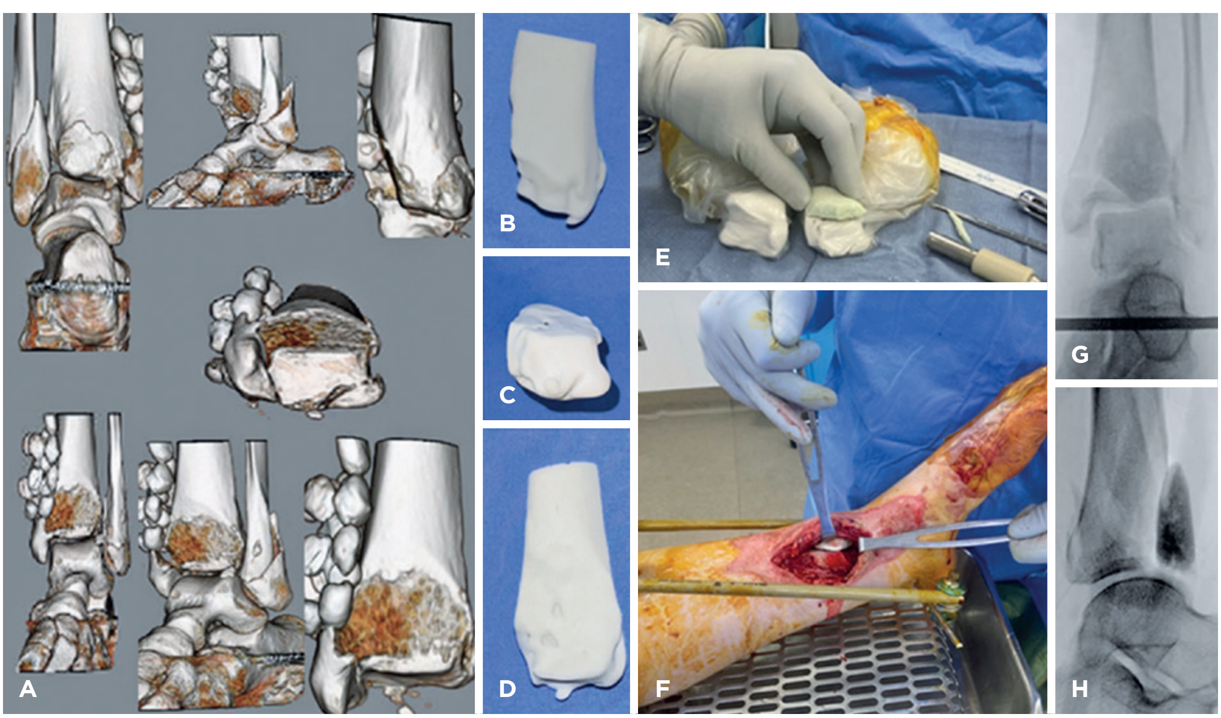

Figure 2. A) 3D CT cuts of the ankle and distal tibia showing distal tibial bone loss and fracture configuration. Note the cement beads on the medial side of the distal tibia B, C, D) 3D printed bone molds. E) The intraoperative clinical photo showing the formation of a cement spacer of the size of the bone defect and fitting it inside the wound. Note that the 3D molds were placed in sterile ultrasound bags. Also, note the right (normal) side mold used to size the spacer in the anteroposterior dimensions. G, H) Intraoperative C-arm radiographs showing properly fitting antibiotic spacer.

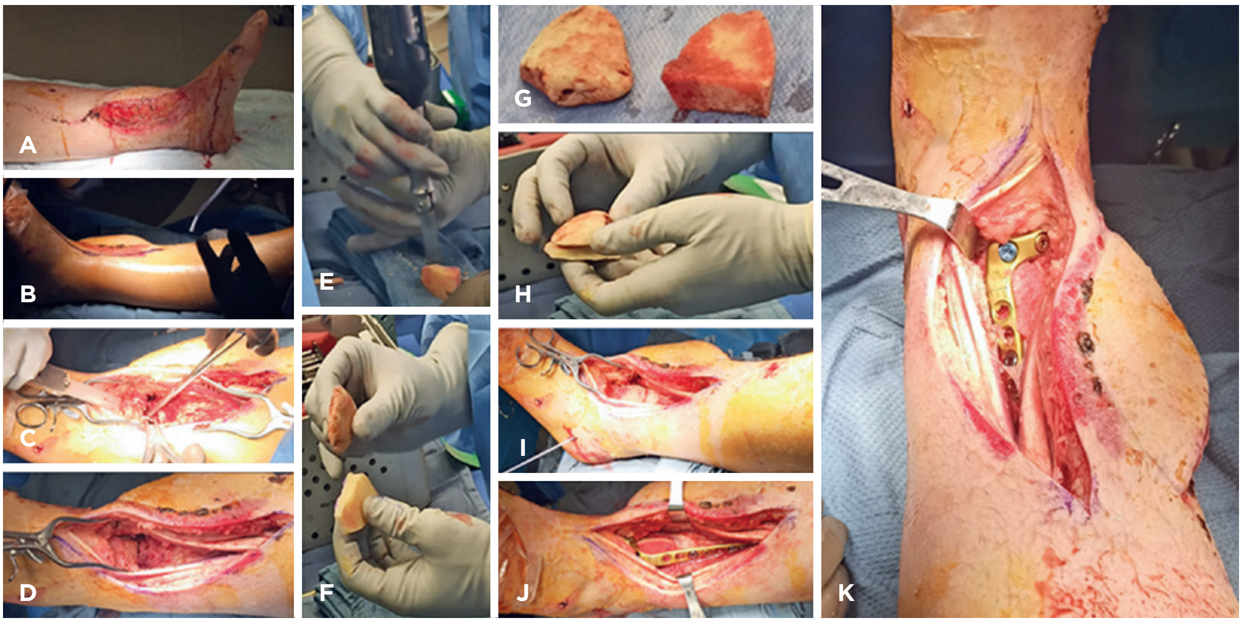

Figure 3. The ankle fusion surgery: A) Condition of the skin flap after external fixator removal. B) Skin marking for the anterolateral incision, lateral to the flap edge. C) After exposure, the articular cartilage is removed using a bone Rongeur. D) The articular surface is devoid of cartilage and drilled. E-H) Shaping and sizing of the allograft to the shape and size of the extracted cement spacer. I) The shaped bone graft fits into the bone defect. J, K) Fixation with anterolateral locking plate and screws over the bone graft.

Figure 4. A-C) Intraoperative C-arm radiographs showing plate placement during the ankle fusion surgery. D, E) A 7-week postoperative plain radiographs showing early progressive consolidation of the fused surfaces. F-H) 12-week, weight-bearing follow-up ankle radiographs showing almost complete fusion. I-K) 19-week, and L-N) 28-week weight-bearing radiographs showing stable fusion construct and complete healing of the fusion surfaces.

graft later in surgery. Several studies reported the success of this technique in acute trauma, particularly in decreasing the need for lengthier and/or potentially demanding reconstruction techniques such as bone transport and vascularized grafts. Hatashita et al.[3] reported seven femoral and tibial open fracture reconstruction cases using the acute Masquelet technique. They reported successful bone union in all of the seven cases despite the occurrence of deep infection in one case. The authors recommended the technique in open fractures with segmental bone loss or partial defects of less than 6 cm[3]. Ronga et al.[5] reported a proximal tibial acute traumatic bone defect of 6 cm in length that was successfully managed with the same technique. Luengo-Alonso et al.[4] reported 12 cases of open femoral and tibial fractures managed with the acute Masquelet technique. Bone consolidation was achieved in all but one case after a mean of 8.4 months. In all of the previous reports, however, none of the cases described subsequent arthrodesis, which was the final management in our case. Our report suggests that the acute Masquelet technique is a reasonable surgical procedure if fusion is planned. This result agrees with other reports highlighting the success of the Masquelet technique before joint fusion in the foot[9,10].

As described, applications of 3DP have been increasingly utilized in orthopedic and spine surgery during the last decade. Their use included manufacturing surgical guides, bone molds, custom-made implants, and bone grafts and scaffolds[6]. Combined with the Masquelet technique, 3DP has created cement spacers in a few reports. For example, Zhang et al. reported four cases of traumatic (three had associated infection) calcaneal bone defects that were reconstructed with the 3DP-guided Masquelet technique to create well-fitting antibiotic PMMA spacers. All the cases were reconstructed in the second stage surgery with bone graft to fill the defects, and successful consolidation was obtained in all cases[7].

In our case, the utilization of in-hospital 3DP helped in performing a sound surgical technique that led to a successful outcome. There are several other independent factors, however, that may have promoted the favorable outcome in this case, such as the patient's medical fitness, repeated surgical debridement, successful soft tissue coverage, and neurovascular integrity.

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Case Report

The Amniotic membrane burrito wrapping technique for surgical repair of closed rupture Tendoachilles - A case report

Amr Ahmed Mahmoud Elshahat[1]

1. Mansoura University, Mansoura, Egypt.

Abstract

After surgical repair of TA rupture, peritendinous adhesions may arise with a potential to re-rupture. The best way to prevent peritendinous adhesions is not well known, even though they can occur after open, mini-invasive, or percutaneous repair procedures. This case report aims to document the efficacy of the human amniotic membrane burrito wrapping (AMBW) technique in repairing acute closed TA rupture over an extended follow-up period, considering tendon healing, gliding, and re-rupture prevention.

Level of evidence IV; Therapeutic studies; Case Report.

Keywords: Tendoachilles, amniotic membrane, stiffness, adhesions, wrapping.

Introduction

Following Tendoachilles (TA) injury repair, postoperative peritendinous adhesions, whether deep or superficial, may develop[1]. TA adhesions impair tendon mobility and gliding, which results in ankle stiffness and adversely affects the outcome of surgical repair. Adhesiolysis may be necessary for deep adhesions that do not improve with physiotherapy. They also have the potential to cause tendon re-rupture[2]. As peritendinous adhesions can follow any type of repair procedure as open, mini-invasive, or percutaneous repair, there is a lack of awareness regarding the best way to prevent them[1,3]. Considering tendon healing, gliding, and re-rupture prevention, the purpose of this study is to document the effectiveness of the human amniotic membrane burrito wrapping (AMBW) technique in repairing acute closed TA rupture over an extended period of follow-up.

Case report

A 43-year-old carpenter who had fallen while climbing stairs showed up in the emergency department with an injury to his left ankle. He didn't have any prior medical issues. The Thompson test was used to make a clinical diagnosis of a Tendoachilles injury. The patient was asked to lie prone and the degree of bilateral ankle plantarflexion was measured after the calf muscle was squeezed[4]. A gap was felt at the tendon insertion into the calcaneal tuberosity. There was no associated neurovascular injury. An avulsion fracture of the calcaneal tuberosity with a thin bony chip was visible on the lateral ankle radiograph (Figure 1A). Magnetic resonance imaging (MRI) confirmed a complete avulsion of tendon form its insertion and proximal retraction of fibers with a 39-millimeter gap (Figure 1). After being made aware of the potential advantages and disadvantages of the procedure, the patient gave his informed consent. The ethics committee of our institution approved the study.

AM preparation

The amniotic membrane was obtained with the written consent of a 33-year-old healthy female patient from our institution's Department of Obstetrics who was scheduled for an elective caesarean section (CS) for her first child, to guarantee its viability and sterility. Before CS, serological

Study performed at Mansoura University, Mansoura, Egypt.

Correspondence: Amr Ahmed Mahmoud Elshahat. Algomhoria Street, 33516, Mansoura University, Egypt. Lecturer of Orthopedic Surgery, Mansoura University, Mansoura, Egypt. **Email:** amrelshahat@mans.edu.eg. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** June 02, 2024. **Date accepted:** July 16, 2024. **Online:** August 30, 2024.

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testing verified her negative status for AIDS, syphilis, and hepatitis B and C. Additionally, the cytomegalovirus test came back negative. Before delivery, the patient had not previously received or donated blood in the previous year.

At the CS, the amniotic membrane (AM) was processed and prepared in a sterile environment. The membrane was gently rinsed after the AM and was meticulously cleaned several times with sterile saline solution to remove any blood clots that adhered to its chorionic surface. After being thoroughly cleaned, the AM was covered in water in a balanced saline solution and treated with antibiotics (Amphotericin, Vancomycin, Neomycin, and Streptomycin) to cover anaerobic, Gram-negative, and Gram-positive bacteria and fungi. Following rinsing, the membrane was placed in an appropriately sized, sterile, airtight container that was filled with 50% glycerol in Dulbecco's Modified Eagle Medium (DMEM, Gibco), along with an equivalent combination of antibiotics. To enable the antibiotics to permeate the tissue and destroy any potential bacteria or other microorganisms, the tissue was then kept at -80°C for the following day(5). The AM was defrosted at room temperature, rinsed with regular buffered saline solution, and kept ready for use before our surgical intervention.

Surgical technique

The patient underwent surgery on the 5th day of injury. The patient received spinal anesthesia. The two legs were prepped and dapped. A tourniquet was raised following the exsanguination of the injured limb. The patient was kept in a prone position. A 12cm vertical incision on the posteromedial side was made, going all the way to the paratenon. The tendon was then attempted to be approximated distally to the calcaneus, ineffectually. stepladder tendon lengthening was done to lengthen the tendon to reach its insertional site (Figure 2). After that, two stitches were used to weave the tendon's vertical limbs together, using non-absorbable sutures (Ethibond number 5).

Approximation of the distal tendon to its insertional site was rechecked compared to the contralateral limb, before taking the stitches. Every time, approximation was made easier by ankle plantarflexion. The distal tendon was debrided, and the edges were refreshened. Care was taken not to injure the sural nerve and the posterior tibial neurovascular structures.

Next, the amniotic membrane placement site was prepared on the bed of the Tendoachilles facing underlying muscles (Figure 3A). The AM was positioned with its smooth surface (amnion surface) facing the soft tissue and skin above and its rough surface (chorion surface) facing the Tendoachilles. The four suture ends of a double-loaded titanium Corkscrew® suture anchor, measuring 5.0 mm, were then ready to pass through the tendon after the suture anchor was inserted into the calcaneus. With the foot placed in plantar flexion, the restoration of appropriate tendon length was guided by the contralateral extremity. Subsequently, the sutures of the anchor were inserted into the tendon in an upward direction, and two knots were fastened to secure the repair.

Next, the AM that had been previously placed was stretched over the entire exposed length of the repaired tendon and wrapped around the Tendoachilles (Figure 3). Using absorbable Vicryl 2-0 sutures, the AM was carefully sewn into the tendon, stretching both the insertional site and the entire length of the exposed tendon. Any excess AM was then excised. Any paratenon remnants were then approximated with the same absorbable sutures. After the tourniquet

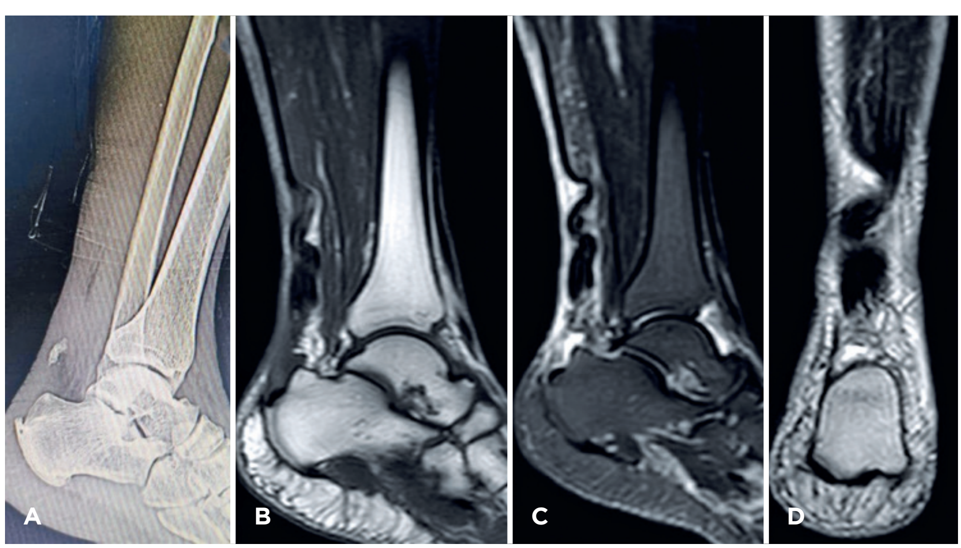

Figure 1. Lateral ankle radiograph (A) shows Tendoachilles avulsion injury from calcaneal insertion. MRI images: sagittal T1 (B), sagittal fat suppression (C), and coronal (D) slices reveal Tendoachilles insertional tear with tendon retraction.

was deflated, proper hemostasis was assured. Prolene 2-0 interrupted sutures were inserted into the skin layer to guarantee careful closure. There was no suction tube placed.

Postoperatively, a posterior back slab splint was applied with the foot at approximately 20 degrees of plantar flexion. Two weeks after surgery, a wound check was performed. Once full skin healing was evident, skin sutures were taken out. After four weeks, the splint was removed, and a controlled action motion (CAM) walker was used to achieve a neutral ankle position. The patient progressed with weight-bearing. Six weeks postoperative, isometric contractions of the gastrocnemius-soleus complex were initiated as the starting point of the rehabilitation program that focused on stretching and strengthening exercises. The patient commenced his daily heavy activities and running after 18 weeks, postoperatively.

The patient's 56-month follow-up was finished. No iatrogenic sural nerve injury, tendon re-rupture, wound infection, or dehiscence were observed during this time. There were no directories of deep or superficial adhesions through the plantar and dorsiflexion of the ankle or heel rise in comparison to the normal ankle (Figure 4). Visible subcutaneous tethering, tightness, or stiffness during tendon movement may be indicative of superficial adhesions. Additionally, deep tendon

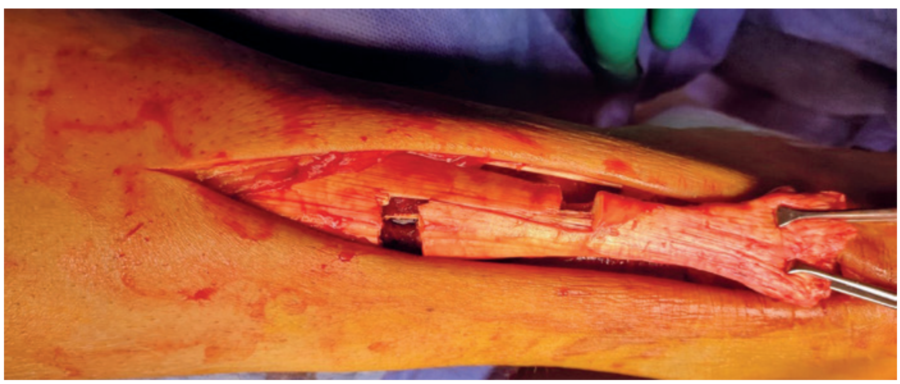

Figure 2. Intraoperative clinical photo after stepladder Tendoachilles lengthening.

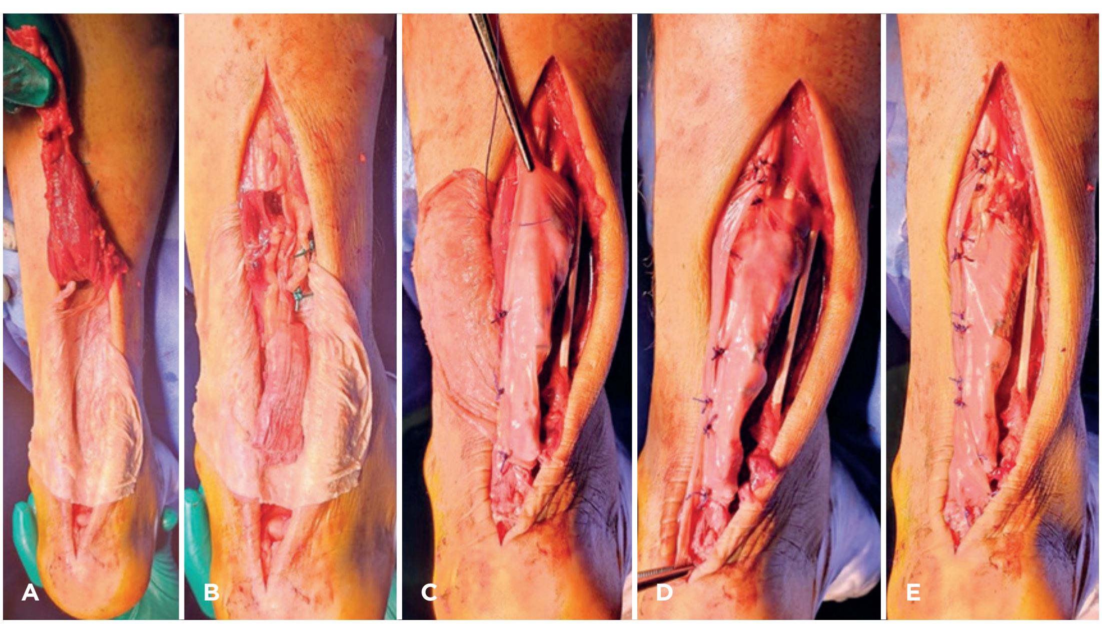

Figure 3. Intraoperative clinical photos demonstrate the AMBW technique: (A) The TA is displaced superiorly, and the AM is placed as a bed for the tendon such that its chorionic surface faces the TA and the amniotic surface faces the underlying tissues and overlapping skin, (B) TA is retained into its position, (C) Following reinsertion of TA into its calcaneal insertion, (D) AM is wrapped and stretched along the entire length of exposed TA, (E) AM is fashioned, secured, and stitched into the TA via absorbable vicryl sutures.

pain associated with decreased ankle range of motion (ROM) due to the tendon's decreased stretchability and elasticity may indicate the presence of deep adhesions[1].

At 6 months, 12 months, and the last visit, the functional status according to the American Orthopedic Foot and Ankle Society (AOFAS) Scale[6] was 78, 99, and 100, respectively. At the last visit, the Achilles tendon Total Rupture Score (ATRS)[7] was 96. The active non- weight bearing ankle (tibiotalar) motion using the orthopedic goniometer revealed active plantar- and dorsiflexion of 44° and 20°, respectively, lower than the contralateral normal tibiotalar motion by 1.5° and 2°. The ankle plantarflexion strength[8] measured with the microFET®2TM digital handheld dynamometer[9] (HOGGAN Industries, Inc., West Jordan, UT, USA) was 534.5 Newtons (N), or 96.4% of the normal side (554.5 N). The maximum calf circumference was assessed using flexible tape in a sitting position with the knee and ankle at a right angle and the feet resting on the floor, at 15 cm below the medial joint line. The calf circumference was 42.5 centimeters with 1.8 centimeters lower than the sound limb. One year after surgery, MRI imaging confirmed the TA integrity and full healing with increased diameter of the repaired tendon (Figure 5).

Figure 4. Clinical photos at final follow-up visit; (A) wound scar, (B) double heel rise revealing no visible subcutaneous tethering or bounce all over the tendon, (C and D) active ankle plantarflexion and dorsiflexion.

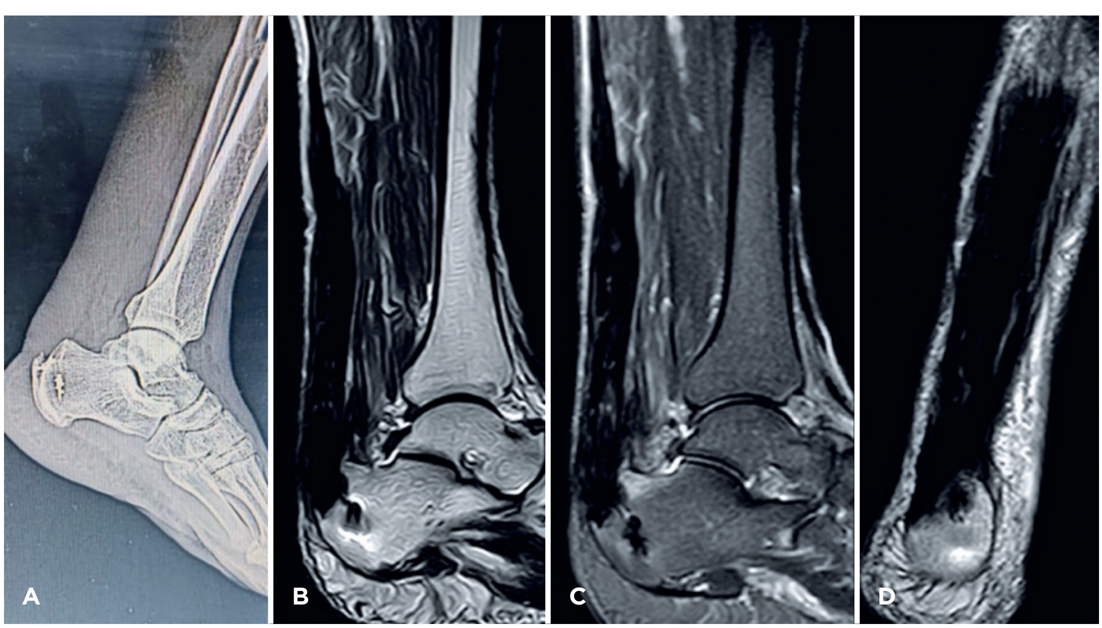

Figure 5. One year postoperative; Lateral ankle radiograph (A) shows restoration of TA continuity to its insertion via an inserted anchor. Sagittal T1 (B), sagittal fat suppression (C), and coronal (D) MRI slices reveal restoration of TA continuity with increased diameter.

Discussion

Peritendinous adhesions with the potential to re-rupture, and wound healing issues may occur after surgical repair of TA rupture[2]. The cuts made during repair to allow for the passage of needles and sutures may result in superficial adhesions. Nevertheless, deep adhesions develop slowly and are easily overlooked; they are frequently incorrectly identified as chronic regional pain syndrome, neurogenic leg pain, or deep vein thrombosis[10]. Deep adhesions primarily result from the tendon remodeling around non-absorbable suture material, which affects the thickness of the tendon[1]. Various surgical strategies, such as minimally invasive and percutaneous repair techniques, have been employed to prevent these postoperative complications[10]. These choices are still insufficient, though.

As previously noted, AM is used in many specialties, including Ophthalmology, Gynecology, Plastic surgery, Gastrointestinal, Neurosurgery, and Orthopedics, to treat a variety of ailments, including wounds, ulcers, burns, and adhesions[11]. Its application demonstrated encouraging outcomes in the healing of peripheral nerves and ulnar nerve transposition revision surgeries[12].

This study employed the AMBW technique as a viable approach to managing acute TA rupture, to functionally regenerate the tissue during the healing process, rather than replacing the defects with scar tissues[13,14]. Along with the excellent outcome in terms of AOFAS & ATRS scores, ROM, calf muscle strength, and an early return to daily activities, the lengthy follow-up period-especially with MRI confirmation of tendon healing-represents a strong point for evaluating this procedure. The healed Tendoachilles showed an increased diameter at MRI slices. This widening may be explained by the membrane circumference itself together with the healed fibers. Morphologically, a surgically repaired tendon can be larger and wider than an intact one[15]. In this case, there were neither postoperative superficial nor deep adhesions. Any surgical technique that allows for earlier tendon healing and mobility can guard against postoperative adhesions and tendon rupture. The AMBW technique is presumed to issue both early tendon mobility and healing.

The concept of using human AM is predicated on its potential for healing, its status as a fully functional biological scaffold, and its cellular composition[14]. Therefore, we can reduce the immune antibody response and the ensuing inflammatory reaction that causes scarring when comparing these advantages to the artificial AM[11]. The AMBW technique might be an option to provide a properly healed tendon within a reasonable postoperative period that permits for early tendon mobility with secure gliding without adhesions, subsequently, this might be beneficial to limit the re-rupture rate.

Conclusion

This case may pave the way for the wider application of the AMBW technique as a low-immunogenic, biocompatible, and affordable procedure, particularly in highly active patients -who refuse conservative management- with medical conditions that impede soft tissue healing. Future clinical studies including large number of patients, with a comparative nature to different surgical options could be more conclusive.

Author' contributions: The author contributed individually and significantly to the development of this article: JD *(https://orcid.org/ 0000-0002-9600-7754) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, performed the surgeries, bibliographic review, survey of the medical records. The author read and approved the final manuscript.*ORCID (Open Researcher and Contributor ID) iD.

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