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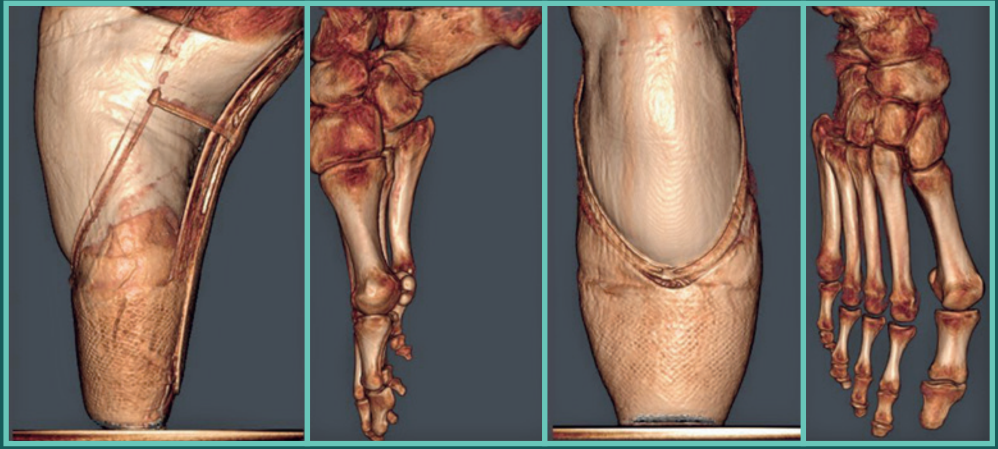

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All about people!

The use of Artificial Intelligence (AI) across a wide range of human activities has been growing rapidly in recent years, becoming an indispensable tool, and science is no exception. However, concern is rising within the academic and scientific communities regarding the misuse of Generative AI in producing scientific papers.

Key concerns include ethical and moral issues, along with the growing risk that it may soon become impossible to distinguish between human-generated and AI-generated content. This challenge is made even greater by the phenomenon known as AI "hallucination," where the system, lacking reliable information, produces entirely fabricated material (texts and data). In addition, AI learning systems are becoming increasingly complex and opaque, making it harder for humans to fully understand and oversee them.

These concerns have been widely discussed within scientific journal editorial boards. One clear conclusion is the need for openness, transparency, and clarity regarding the use of AI. Authors are now expected to disclose, at the time of submission, whether AI tools were used and specify in which activities (such as drafting, language editing, translation, or creation), particularly when Generative AI is involved. This information will undergo technical review to assess its impact on the submitted work and will be shared with reviewers, potentially influencing the evaluation and acceptance process. Among the many daily challenges, this is one of the newest—and certainly one of the most complex[1,2].

This issue of the Journal of the Foot and Ankle marks the debut of our "online first" publication model, allowing readers early access to articles as soon as the review, correction, and editorial stages are completed. This achievement was made possible thanks to the collaborative efforts of authors, reviewers, the technical editorial team, translators, and designers. ABTPé, through its board and administrative staff, played a crucial role by dedicating significant effort and resources to this endeavor. We extend our heartfelt thanks to everyone involved.

We remain committed to further improving our editorial processes, always striving for the highest standards of scientific integrity, transparency, and efficiency.

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Special Article

The role of subtalar arthroereisis in flatfoot treatment: insights from weight-bearing computed tomography

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Abstract

Flatfoot is a common deformity in adult and pediatric populations, with a 5% incidence. The three-dimensional deformity and the dynamic joint behavior during weight bearing are better understood with weight-bearing computed tomography (WBCT), making it an essential tool for diagnosis and staging. There is consensus about the indication for arthroereisis in symptomatic flexible flatfoot or hindfoot valgus in pediatric or adolescent populations; however, no studies to date have evaluated the degree of three-dimensional correction achieved in adult patients with progressive collapsing foot deformity (PCFD) treated with arthroereisis. A retrospective analysis of nine adult patients with symptomatic flexible flatfoot (15 feet) submitted to arthroereisis, was performed. WBCT before surgery and four months after the procedure were reviewed. Subtalar and talonavicular joint alignment was analyzed through specific measurements (Inftal-suptal, Inftal-hor, posterior facet subluxation, medial facet subluxation, calcaneal pitch, Meary's angle, dorsal talar-1st metatarsal angle, and talonavicular angle). Inftal-hor, posterior facet subluxation, medial facet subluxation, Meary's angle, dorsal talar-1st metatarsal angle, and talonavicular angle reached statistically significant differences. The talonavicular coverage angle showed a more considerable improvement with a mean of 33º in the preoperative vs 23º in the postoperative ($p < 0.001$). Calcaneal inclination ($p = 0.195$) and Ifthal-suptal ($p = 0.656$) had no statistical differences. Subtalar arthroereisis is an effective three-dimensional correction procedure for adults with symptomatic progressive collapsing foot deformity.

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

Keywords: Subtalar Joint; Flatfoot.

Introduction

Progressive collapsing foot deformity (PCFD) is common in adult and pediatric populations, with an estimated incidence of 5% in the general population[1]. Hindfoot valgus, calcaneal pronation, forefoot abduction, and medial plantar arch flattering make this three-dimensional deformity challenging for foot and ankle surgeons[2,3]. In many cases, joint dynamic behavior during walking could be asymptomatic and not require any corrective interventions. Staged management is initiated when the pathology's progressive nature becomes symptomatic[4].

Conservative treatment includes shoe or insole modifications, physiotherapy, and changes in daily activities. In cases of conservative management failure, surgical treatment is considered. Options include tendon transfers, calcaneus or midfoot correction osteotomies, and subtalar or talonavicular joint arthrodesis, and, in some patients, arthroereisis appears to be a good option[5].

Over the years, subtalar arthroereisis has gained popularity in hindfoot valgus correction with a mechanical block of eversion. Inversion remains flexible, and the subtalar joint (STJ) remains unfused, thereby improving the secondary adaptation of the forefoot and hindfoot on uneven ground.

There have been several arthroereisis implants since its first description by Grice[6]. Vogler[7] classified the subtalar implants into three types, based on their biomechanical characteristics: axis-altering devices, impact-blocking devices, and self-locking wedges; the latter being the most used nowadays[8]. Several publications suggest that symptomatic flexible flatfoot or hindfoot valgus in pediatric or adolescent patients

Study performed at the Clínica Universidad de los Andes, Facultad de Medicina Universidad de los Andes, Santiago. Chile.

Correspondence: Cristian Ortiz. Av Plaza 2501, Las Condes, Región Metropolitana, Chile. **Email:** caortizm@gmail.com **Conflicts of interest:** None. **Source of funding**: None. **Data received:** March 22, 2025. **Data accepted:** April 15, 2025.

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is the main indication for this procedure[9]. Although weight-bearing radiographs are mandatory for the initial assessment and surgical planning, they have limitations in bone morphology and three-dimensional joint relationships[10,11].

Weight-bearing computed tomography (WBCT) has become a valuable tool to identify and optimize staging in foot and ankle deformities[12-14], solving the problem of conventional CT scans[11]. WBCT provides a better understanding of biomechanical behavior and foot anatomy in all planes by enabling more accurate extrapolation from static images[15]. At the same time, STJ valgus deformity, sinus tarsi, and/or subfibular impingement could be assessed[16].

After the first publication of WBCT in 2014[17], new radiological parameters have been described to understand PCFD better, like STJ orientation[15] associated with the talonavicular coverage angle[18].

The objective of this study is to present preliminary findings on the radiological correction observed in adult patients submitted to isolated arthroereisis, evaluated using WBCT, before surgery and four months postoperatively. We hypothesize that arthroereisis achieves adequate three-dimensional correction of the subtalar and talonavicular joints.

Methods

In this retrospective clinical study, pre- and postoperative changes were evaluated in adult patients with flexible PCFD submitted to arthroereisis. Subtalar joint, subtalar and talonavicular subluxation degrees were addressed with pre- and postoperative WBCT. Low-demand patients older than 18 years with symptomatic flexible flatfoot (subfibular impingement or medial pain) who have failed conservative treatment and have undergone arthroereisis as a primary procedure from June 2020 to June 2021 were included. Exclusion criteria were patients exhibiting a rigid STJ upon physical examination, previous history of foot and ankle surgery, known hindfoot or ankle osteoarthritis, patients requiring additional corrective osteotomy, or those in whom arthroereisis has been used as a complementary procedure to another surgical technique. The minimal follow-up period was 12 months. The analysis of the subtalar and midfoot orientation was performed on pre- and postoperative WBCT through the following radiological parameters.

Hindfoot alignment

A. Inftal-suptal: the angle formed by a tangent passing through the tibiotalar articular surface (talar surface) and the talar articular facet of the STJ at its point of greatest width (Figure 1a and 1b).

B. Inftal-hor: the angle formed by a tangent passing through the talar surface of the STJ at its point of greatest width and the horizontal (Figure 1c).

C. Posterior facet STJ subluxation: percentage of uncovering of the talar articular surface of the posterior facet of STJ concerning the calcaneal articular surface at its point of greatest width (Figure 2a).

D. Medial facet STJ subluxation: percentage of uncovering of the talar articular surface of the medial facet of STJ at its point of greatest width (Figure 2b).

E. Calcaneal pitch: the angle formed by a tangent passing through the horizontal plane and the inferior wall of the calcaneus.

Midfoot alignment

Talonavicular coverage: the angle between the articular surface of the head and the proximal articular surface of the navicular, measured on an axial reconstruction aligned with the foot axis that includes both structures in the imaging slices.

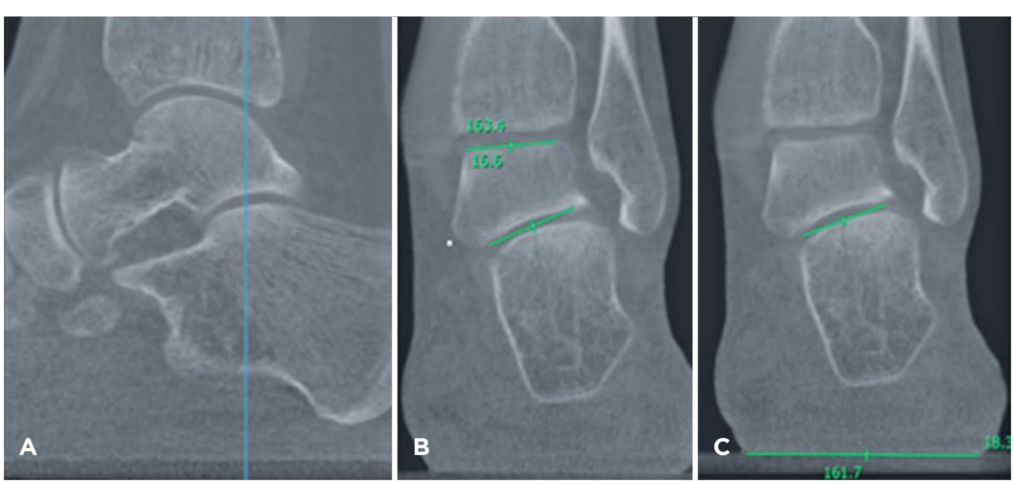

Figure 1. Angular measurements and subluxation parameters used in the three-dimensional assessment of the hindfoot using weight-bearing computed tomography (A). (B) Inftal-suptal. (C) Inftal-hor.

Lateral talar-1st metatarsal angle (Meary's angle): the angle between a line drawn along the longitudinal axis of the talus and the 1st metatarsal (1st metatarsal axis) in a reconstruction that includes both structures in the imaging slices.

Dorsal talar-1st metatarsal angle: a line is drawn down the longitudinal axis of the 1st metatarsal to form an angle with a second line along the longitudinal axis of the talar articular surface or talar neck, in an axial reconstruction aligned with the foot axis that includes both structures in the imaging slices.

Images were evaluated using the Enterprise Imaging XERO Viewer 8.1.2 software (Copyright (c) 2019 Agfa HealthCare N.V.). All measurements were performed by a single foot and ankle fellowship-trained in reconstruction. Reconstruction was performed on the foot anatomical axis in coronal, sagittal, and axial planes.

Statistical analysis

The variables were described with statistics measuring central tendency (medians, means, and percentages). To establish the type of distribution of the resulting data, the Shapiro-Wilk test was used. T-test or equivalent non-parametric Wilcoxon test was performed in the cases where the difference of pre- and postoperative variables measurements (Inftal-hor, Inftal-suptal, medial facet subluxation, posterior facet subluxation, calcaneal pitch, dorsal talar-1st metatarsal angle and lateral talar-1st metatarsal angle, midfoot alignment, talonavicular coverage angle) did not follow a normal distribution. All analyses considered an alpha of 5% ($p < 0.05$). The statistical analysis was performed using SPSS version 27. Due to the lack of existing literature or evidence to support a power calculation of our sample size for our intervention, the sample size was defined as the total number of patients operated on from June 2020 to June 2021 with pre- and postoperative WBCT. With the resulting data, a calculation of post hoc power was performed.

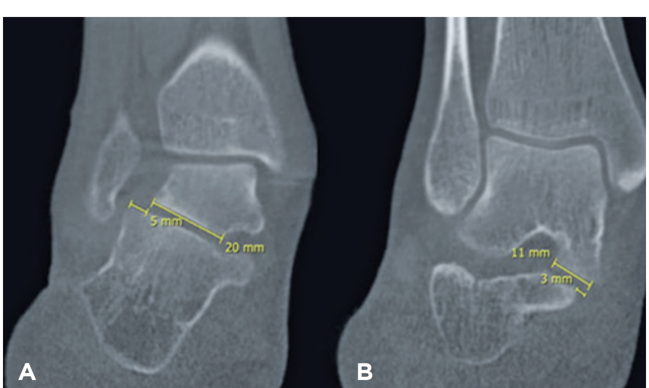

Figure 2. Subluxation measurements of the subtalar joint. (A) Posterior facet of the subtalar joint subluxation. (B) Medial facet of the subtalar joint subluxation.

Results

Nine patients were included, six of whom had bilateral surgery, totaling 15 feet (Table 1).

Thirteen feet showed a significant correction of the parameters evaluated. All the assessed measurements showed significant differences with pre- and postoperative WBCT comparatively, except the calcaneal pitch angle ($p = 0.195$) and Inftal-suptal ($p = 0.656$) which, with the numbers available, no significant difference could be detected, being the talonavicular coverage angle the one that showed the greatest change with a mean of 33º in the preoperative to 23º in the postoperative ($p < 0.001$). Table 2 summarizes the complete statistical analysis of the variables analyzed.

Clinical case

A 79-year-old male patient was diagnosed with PCFD. The patient presented a one-year history of pain associated with the posterior tibial tendon. Despite undergoing physical therapy and using orthotic insoles for eight months, he experienced minimal relief from his symptoms. A thorough physical examination revealed valgus positioning of the hindfoot, a flexible STJ with a positive heel rise test, and localized pain and inflammation along the posterior tibial tendon, exacerbated upon palpation of the retro-malleolar area (Figure 3a and 3b).

Weight-bearing computed tomography studies demonstrated a flatfoot deformity with no advanced signs of

Table 1. Demographic and clinical characteristics of the study population

Number of patients	Male sex, n (%)	Mean age, y	Bilateral side (%)
15	6 (40%)	39.06	6 (40%)

Table 2. Summary of the statistical analysis of the evaluated variables

	Preoperative (SD)	Postoperative (SD)	p
Iftal-hor	14.88 (4.99)	8.57 (3.81)	0.046
Iftal-suptal	16.986 (4.08)	10.373 (4.69)	0.656
Subtalar lateral medial facet	41.633 (15.8)	24 (10.55)	0.000
Subtalar lateral posterior facet	18.8 (6.58)	9.866 (6.82)	0.001
Calcaneal pitch	12.586 (5.82)	15.493 (6.63)	0.195
Dorsal talar-1st metatarsal angle angle	17.193 (9.8)	10.04 (5.34)	0.014
Meary's angle	21.426 (11.49)	13.893 (5.86)	0.003
Talonavicular coverage	33.994 (17.4)	23.7 (8.72)	0.001

SD: Standard deviation.

joint degeneration observed in the subtalar, tibiotalar, or talonavicular joints. Before the WBCT, all patients underwent radiographic evaluation using weight-bearing anteroposterior, lateral, and oblique views, as well as comparative Saltzmann radiographs. Notably, patients were not routinely studied with magnetic resonance imaging (MRI). The following angular measurements from the WBCT were: Dorsal talar-1st metatarsal angle at 18°, lateral talar-1st metatarsal angle at 13.8°, calcaneal inclination angle at 7.8°, talonavicular coverage angle at 44.2°, Inftal-hor at 18.3°, Inftal-suptal at 20.1%, with the subtalar lateral medial facet at 51%, and the subtalar lateral posterior facet at 22%.

Surgical technique

The patient was submitted to isolated arthrorisis for surgical correction while in a supine position with a bolster under the ipsilateral gluteus to maintain the lower extremity in a neutral position. The procedure was performed under local anesthesia with sedation. A 1 cm incision was made over the sinus tarsi (Figure 4), and a guiding K-wire was inserted toward the tip of the medial malleolus, with its position confirmed through fluoroscopic imaging. Accurate placement of the K-wire was verified through anteroposterior, lateral, and the Broden view projections.

A cannulated trial was introduced through the guiding K-wire, advancing progressively to ensure a firm fit without excessive STJ distraction, which was confirmed on lateral-view imaging. The implant size was determined and positioned through the guiding K-wire (Figure 5a), ensuring it remained secure without distracting the STJ and aligned with the lateral contour of the talar neck in the anteroposterior view (Figure 5b and 5c). Notably, during the implant positioning, a clinical change in the three-dimensional disposition of the foot was observed, along with a noticeable limitation in the excursion of the STJ when forced into valgus. Following the procedure, the skin was closed with simple interrupted sutures, and a small adhesive dressing was applied to the surgical site to aid in the healing process (Figure 6). The patient was instructed to bear weight as tolerated immediately after the procedure, outfitted with a postoperative orthotic shoe, and scheduled for suture removal between the second and third postoperative weeks.

At the fourth month postoperative follow-up, the WBCT measurements were as follows: dorsal talar-1st metatarsal angle angle was 12.7°, lateral talar-1st metatarsal angle was 12.6°, the calcaneal inclination angle was 15.5°, and the talonavicular coverage angle was 10.5°, Inftal-hor 10.4°, Inftal-suptal 10.8°, subtalar lateral medial facet 43% and subtalar lateral posterior facet 20.7% (Figure 7).

The patient improved satisfactorily, and on the fourth-month control visit, he reported being able to perform all his daily activities. Notably, pain related to the posterior tibial tendon decreased significantly from 6/10 to 2/10 on the visual analog scale (VAS).

Discussion

Arthroereisis was first described by Grice in 1952[6] for treating flatfoot in children; however, it was abandoned due

Figure 3. Hindfoot valgus.

Figure 4. Sinus tarsi approach.

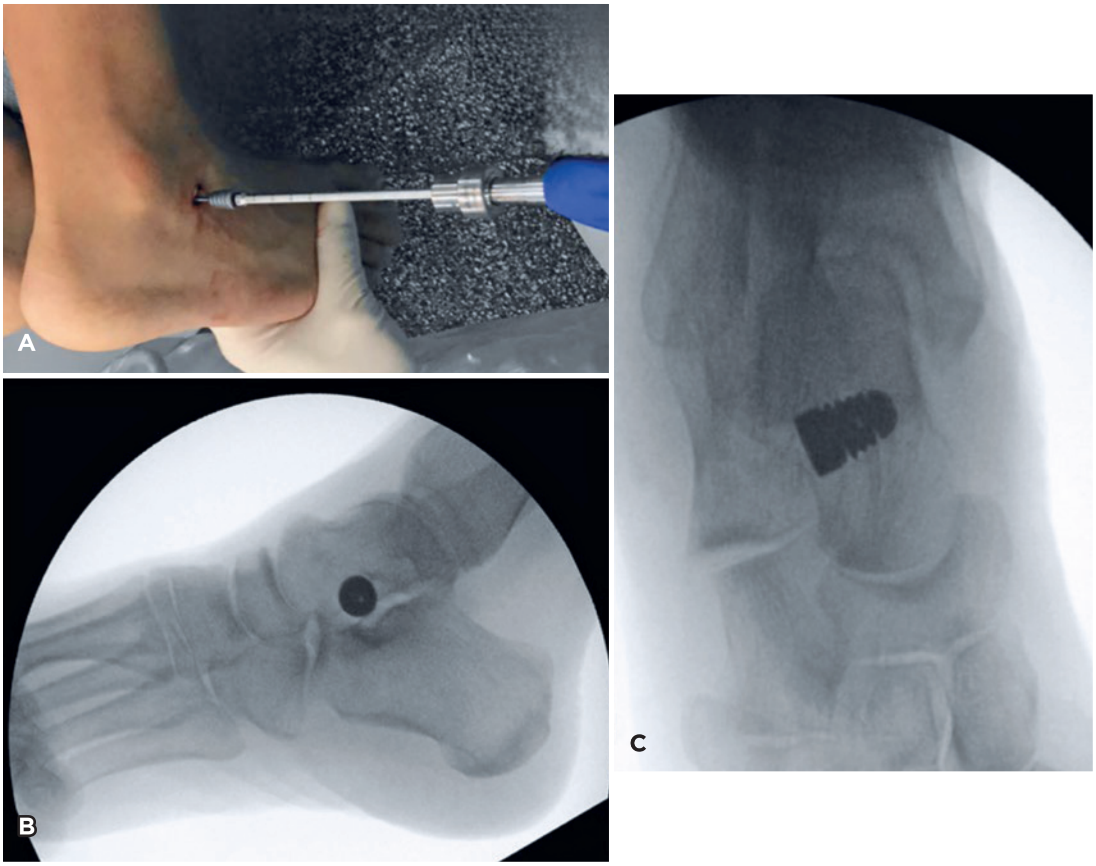

Figure 5. (A) Implant positioning. (B) Subtalar joint with no distraction. (C) Implant base aligned with the lateral contour of the talus neck.

Figure 6. Final aspect of the surgical site after closure with simple interrupted sutures and application of a small adhesive dressing to promote healing.

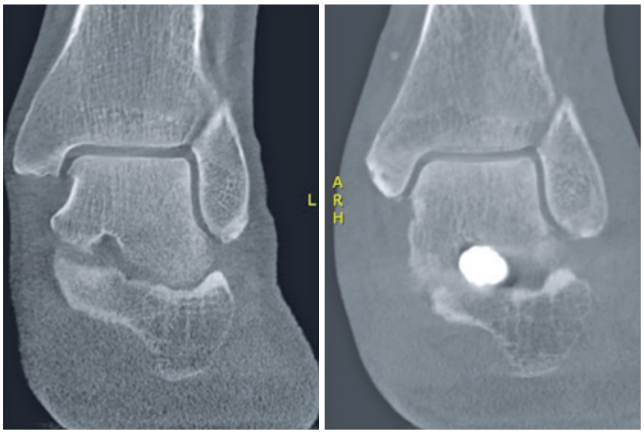

Figure 7. Weight-bearing computed tomography measurements at four months postoperatively, showing angles and subluxation percentages indicative of three-dimensional correction.

to the high rate of complications, loss of correction, and implants removal. Viladot[19] was the first to describe a sinus tarsi implant that showed success near 99% in the pediatric population, even without correction loss after removing hardware. Subsequently, Pisani[20] described the concept of glenopathy of the coxa pedis in which flatfoot generates an insufficiency of medial structures. This concept applies similarly in the pediatric and adult populations. Since the apex of the deformity is at the level of the STJ, generating an eversion and external rotation of the calcaneus leading to plantar flexion of the talar head, arthroereisis acts precisely at this site, providing a mechanical blocking of this phenomenon. Viladot et al.[21] studied 35 patients with flexible flatfoot deformity submitted to arthroereisis combined with soft tissue repair, demonstrating that 74% achieved good to excellent outcomes. Follow-up assessments using weight-bearing radiographs revealed significant correction in dorsal angle, Kite angle, Moreau-Costa-Bartani angle, and talonavicular coverage angle. One-third of the patients required implant removal due to associated pain.

Silva et al.[22] compared lateral column osteotomy and subtalar arthroereisis for Grade IIB adult-acquired flatfoot deformity. At 24 months, both achieved comparable radiological correction, but lateral column osteotomy showed superior clinical outcomes on the American Orthopaedic Foot and Ankle Society and VAS scales and a significantly lower complication rate (4.4% vs 20.6%). While subtalar arthroereisis provides a less invasive surgical approach, lateral column osteotomy demonstrated superior long-term functional outcomes in this study.

Stichnoth et al.[23] compared subtalar arthroereisis, medializing calcaneal osteotomy, and combined for adult flatfoot: all three significantly improved patient-reported outcomes and radiographic parameters. The combination provided superior radiographic correction, especially in severe cases. Pedobarographic analysis showed comparable gait in treated and untreated feet. While subjective improvements were similar, objective data favored subtalar arthroereisis and the combination, suggesting the latter as potentially superior for severe adult flatfoot.

Lewis et al.[24] studied a retrospective cohort of 212 feet treated with subtalar arthroereisis for stage 1 PCFD. Postoperative Foot and Ankle Outcome Scores demonstrated statistically significant improvements across all domains at a mean 2.5-year follow-up. A substantial 48.1% implant removal rate was observed, primarily due to persistent sinus tarsi pain. Comparing outcomes between patients with and without implant removal revealed no significant differences in functional measures at the final follow-up. These results suggest that subtalar arthroereisis provides clinically meaningful functional gains in stage 1 PCFD despite a high rate of subsequent implant removal.

Based on the literature and the author's experience, arthroereisis plays a crucial role in managing PCFD, not only in combined surgical interventions but also in isolation. This hypothesis aligns with the results demonstrated by three-dimensional measurements in WBCT.

Our study presents 15 feet with a good percentage of correction in 86.6 % of cases, despite requiring implant removal.

In our series, of the total variables evaluated, only 2 (posterior facet subluxation and calcaneal pitch) showed a non-normal distribution, showing significant differences for posterior facet subluxation in the analysis of WBCT pre- and postoperative ($p < 0.001$), with the Wilcoxon test. All the other variables followed a normal distribution, and their differences were evaluated with a t-test. Regarding the conventional parameters, the talonavicular coverage, the dorsal talar-1st metatarsal angle, and Meary's Angle showed significant changes in the WBCT at four months. When analyzing the variables that evaluate the subtalar joint orientation and the degree of peritalar dislocation (Iftal-hor, Iftal-suptal, subtalar lateral medial facet), all variables showed a statistically significant change ($p < 0.01$) from the preoperative measures with t-test, except for Iftal-suptal, which did not show significant differences ($p = 0.656$). In addition, our patients presented an incidence of symptomatic hardware of 20%; two patients required implant removal, one of those bilateral (3 feet), showing no improvements after one attempt at conservative treatment with local infiltration at six months. Fortunately, we did not obtain any loss of correction assessed by WBCT at the final follow-up of at least 24 months.

Additionally, and as the main objective of this novel study, we describe the behavior of the hindfoot assessed by WBCT four months after arthroereisis, focusing on the degree of three-dimensional correction achieved with this technique in adults, both in the subtalar and talonavicular joints. For our measures, it was decided to use the classically described variables, as well as the analysis of new measurements recently described and performed with WBCT for the evaluation of the subtalar joint such as the center of rotation of angulation of the deformity, including the subluxation of the medial and posterior facet of the STJ[25] together with the evaluation of the orientation of the STJ, according to the methods described (Iftal-hor, Iftal-suptal)[15]. Our report describes a significant three-dimensional correction of the variables measured at the subtalar and talonavicular joints level, except in two patients who did not achieve correction. Both required implant removal, and one was submitted to surgery with an Evans osteotomy and medial displacement calcaneal osteotomy, after which an adequate correction was achieved.

Our study is not without its limitations. Firstly, the absence of a comparative control group limits our ability to ascertain whether the percentage of correction achieved aligns with that observed in other interventions. Secondly, we could not establish a correlation between the functional scores (PROMIs) and the degree of correction attained in our patient cohort. Furthermore, this study represents a small case series, which restricts the strength of our conclusions and the establishment of a management protocol incorporating arthroereisis as a viable alternative. We also acknowledge that a four-month follow-up using WBCT may be relatively short, considering the chronic nature of this pathology. However, we believe this timeframe is sufficient to assess the foot's accommodation following surgical correction, as all patients commenced weight-bearing as tolerated in the immediate postoperative period.

The minimal invasiveness and short surgical time allow an early return to daily activities and do not burn any bridges for future treatment modalities. As discussed previously, the most striking complication is the potential hardware removal. The results are left unaffected. More evidence is still required to reach a better conclusion regarding arthroereisis in younger individuals. For the adult patient population, indications are even more confusing. Still, it seems reasonable to consider arthroereisis as a complement to other techniques to protect the medial soft tissue reconstructions or help improve corrective power associated with different kinds of osteotomies, or consider it as an isolated low-risk minimally invasive technique in patients who do not want aggressive reconstructions[26].

Conclusions

Subtalar arthroereisis is an effective treatment alternative for acquired flatfoot in adults, which achieves an adequate three-dimensional correction observed with WBCT in multiple parameters that affect both the orientation of the subtalar and talonavicular joints, achieving significant correction of all the parameters evaluated, except for the Iftal-suptal and the calcaneal pitch. Furthermore, we are continuing to study and monitor our patients with WBCT to expand our sample size and the results to be presented in future analyses.

Authors' contributions: Each author contributed individually and significantly to the development of this article: CO *(https://orcid.org/0000-0003-2574-9010), and OE, and EP Conceived and planned the activities that led to the study, wrote the paper, participated in the reviewing process. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Special Article

The search for the holy grail in cavovarus foot

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Abstract

Introduction: The surgical treatment of cavovarus foot is complex and multifactorial, requiring a personalized approach that respects its biomechanical and neuromuscular intricacies. Despite numerous techniques described, achieving a plantigrade, pain-free, and functionally stable foot remains the ultimate goal—the so-called "holy grail" of treatment.

Methods: This narrative review outlines a stepwise strategy for the surgical correction of cavovarus foot, emphasizing the role of soft tissue releases, tendon transfers, osteotomies, and fusions. The intervention sequence is tailored according to deformity flexibility, apex location, and muscular imbalance patterns, drawing from principles refined in managing Charcot-Marie-Tooth disease and adapted to other etiologies.

Results: Adequate soft tissue release—especially of the Achilles tendon, plantar fascia, and medial restraints—precedes osseous realignment. Tendon transfers, such as those involving the posterior tibial tendon or peroneus longus, aim to neutralize deforming forces and preserve correction. Decisions between osteotomy and arthrodesis hinge on the rigidity and anatomical apex of the deformity, often requiring midfoot realignment. Toe deformities, particularly hallux malleus, are addressed through targeted techniques like the Jones procedure, following proximal correction.

Conclusion: Successful reconstruction of the cavovarus foot depends on a dynamic, intraoperatively responsive algorithm that integrates functional muscle assessment, sequential releases, and appropriate structural correction. Lessons learned from neuromuscular cases contribute significantly to optimizing outcomes in idiopathic or post-traumatic deformities.

Level of evidence V; Experience-Based Expert Opinion.

Keywords: Cavovarus foot; Charcot-Marie-Tooth disease; Tendon transfer; Osteotomy; Arthrodesis; Foot deformity.

Introduction

The quest for an ideal treatment for cavovarus foot has been a constant challenge. Traditionally, the "holy grail" in managing this complex deformity has been restoring muscle balance, aiming to correct biomechanical changes and alleviate symptoms. However, the growing understanding of the influence of neuromotor dysfunction, especially Charcot-Marie-Tooth disease (CMT), in the etiology of cavovarus foot has challenged this classic view[1,2].

Cavovarus foot, characterized by an elevated medial longitudinal arch, hindfoot varus, and forefoot pronation and adduction, is frequently associated with a variety of conditions, including lateral ankle instability, fifth metatarsal stress fractures, and fibular tendinopathies[3]. Although muscle imbalance is a well-established etiological factor, recent studies have shown that CMT is present in a significantly higher percentage of patients with cavovarus foot than previously thought[2].

This narrative review proposes a new perspective: the true "holy grail" does not lie in the complete restoration of muscle balance—an often-unattainable goal—but rather in clinical reasoning centered on this concept, considering the influence of neuromotor dysfunction and the multifactorial etiology of the deformity[4]. By considering the underlying neuromotor basis, the treatment of cavovarus foot should follow an evolutionary algorithm, starting with a comprehensive

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diagnostic evaluation, including the identification of mechanical deformities[1,3], the analysis of the biomechanics inherent to the observed muscle imbalances, and the investigation of neuromotor pathologies, with emphasis on CMT[2].

Therapeutic options range from conservative approaches, such as physical therapy and the use of orthotics, to surgical interventions. Decisions about surgical treatment are based on the rationale of muscle balance and progress from restorative techniques with tendon transfers and osteotomies to reconstructive surgeries with arthrodesis and, in selected cases, arthroplasties[5]. The complexity of cavovarus foot requires an individualized approach, intending to create a plantigrade, mobile, stable, and pain-free foot[1].

In this narrative review, we will explore the reasoning behind this new perspective of the "holy grail" of cavovarus foot, which is based on the functional analysis, detailing the diagnosis from the triad of deformity, biomechanics, and neuromotor dysfunction, and, based on this framework, define the best therapeutic approach, based on known techniques and tools. The objective is to achieve a plantigrade, stable, and pain-free foot, capable of sustaining a functional gait and preserving the maximum joint mobility.

Observed mechanical deformities

Mechanical deformities are a pillar in diagnosing cavovarus foot, guiding the understanding of the altered anatomy and biomechanics that sustain the pathology. The evaluation begins with a visual inspection and a detailed physical examination, essential elements to delineate the morphological profile of the foot[1,6]. The increase in the medial longitudinal arch, for example, manifests as a marked characteristic of the plantar curvature. Assessing the flexibility of this elevation is a crucial point to determine, as a rigid arch may signal more complex underlying structural or neurological causes, while a flexible arch may indicate greater responsiveness to conservative therapeutic approaches[3].

The forefoot presents supination and adduction in relation to the hindfoot, configuring an atypical load distribution pattern, leading the hindfoot to a varus deformity, contributing to a greater overload on the lateral column of the foot[3]. The frequent presence of claw toe deformities, especially in the hallux, derives from the imbalance between the intrinsic and extrinsic musculature of the foot[6]. Observing callosities in specific areas, such as the lateral region of the foot, metatarsal heads, and the dorsal aspects of the interphalangeal joints, reinforces these points of overload and excessive plantar pressure[7].

The overall flexibility of the foot is a crucial determinant, influencing the choice of therapeutic strategy. The Coleman block test offers valuable insights into the influence of the first ray on the hindfoot deformity. The elevation of the first ray during single-leg stance allows verifying whether the correction of the hindfoot varus is possible, indicating the flexibility of the deformity and the relevance of the first ray in its pathogenesis[6].

Radiographic evaluation offers a detailed view of the bone alignment and the intrinsic anatomical relationships of the foot. Weight-bearing radiographs, in anteroposterior and lateral views, are indispensable to measure angles such as Meary's angle, which assesses the sagittal alignment of the foot, Hibbs' angle, which assesses the sagittal alignment of the hindfoot, in addition to the calcaneal pitch, which estimates the height of the medial longitudinal arch[3]. The Saltzman view radiograph also provides important information regarding the analysis of the axial axis of the calcaneus in relation to the tibial axis, evidencing the degree of hindfoot varus (Table 1).

In selected cases, weight-bearing computed tomography (WBCT) emerges as an advanced diagnostic tool, offering a detailed three-dimensional assessment of the bone anatomy and joint relationships of the foot and ankle under weight-bearing conditions. WBCT allows identifying subtle and complex deformities that may not be evident in conventional radiographs, in addition to providing valuable information about weight-bearing distribution and joint alignment[8]. This imaging modality can be particularly useful in surgical planning, allowing a precise assessment of deformities and the simulation of different correction approaches.

Biomechanics of cavovarus foot: integrated analysis of structure and function

The biomechanics of the cavovarus foot are intrinsically linked to its structural morphology, which manifests as an increase in the height of the medial longitudinal arch and, frequently, a hindfoot varus. This particular bone conformation directly influences the distribution of plantar pressures during the gait cycle, resulting in a characteristic pattern of overload in the lateral region of the foot and the metatarsal heads, as demonstrated by Fernández-Seguín et al.[9]. The analysis of the kinematics of the cavovarus foot reveals a lower ankle dorsiflexion and an increase in hindfoot inversion during the stance phase, which, according to Williams et al.[10], may contribute to joint instability and

Table 1. Radiographic measurement angles assessed in cavovarus foot evaluation

Measurement	Description	Cavus foot
Meary angle	• Talus axis • First metatarsal axis	• Negative (plantar flexion of the first ray)
Arch height	• Base of the medial cuneiform • Base of the fifth metatarsal	• < 14 mm (plantar flexion of the first ray) • Normal ≈ 10 mm
Fibula position	• Fibula position relative to the tibia	• Posterior (ankle in varus)
Calcaneal pitch angle	• Plantar surface of the calcaneus • Support plane	• Increased (usually > 30°)

increase the susceptibility to lateral ankle sprains. In addition, the assessment of the flexibility of the first ray and the strength of the intrinsic muscles of the foot are important components of the biomechanical analysis, as they can influence the progression of the deformity and the response to conservative treatment. The use of computational models and biomechanical simulations has been promising in evaluating the biomechanics of the cavovarus foot, allowing the analysis of different scenarios and the planning of personalized interventions.

The multi-segment foot model, proposed by Stebbins et al.[11], represents a valuable tool for the detailed analysis of the kinematics of the cavovarus foot, allowing the evaluation of the relative movement between the different bone segments. This model has demonstrated that the cavovarus foot presents a greater stiffness of the medial longitudinal arch and a greater compensatory mobility between the hindfoot and the midfoot. This greater compensatory mobility may be an attempt to absorb the impact and adapt the foot to different surfaces, but it can also lead to an overload of the midfoot joints. The analysis of muscle activity during gait can also provide important information about the biomechanics of the cavovarus foot. The evaluation of the strength and endurance of the intrinsic muscles of the foot is also important, as these muscles play a fundamental role in stabilizing the medial longitudinal arch and controlling foot pronation and supination.

The influence of the height of the plantar arch on the biomechanics of the lower limbs during running has been widely investigated. Studies have shown that individuals with cavovarus feet tend to present a greater ankle pronation and internal rotation of the tibia during running, which may increase the risk of injuries such as medial tibial stress syndrome and iliotibial band syndrome, as demonstrated by Nielsen et al[12]. The analysis of the ground reaction force during running reveals that cavovarus foot presents a more abrupt impact pattern, with a higher peak vertical force and a shorter contact time with the ground, which may indicate a lower capacity to absorb impact and a greater overload on the joints of the lower limb, as demonstrated by Cavanagh and Lafortune[13]. Using foot orthoses can alter the biomechanics of the cavovarus foot, reducing plantar pressure in the lateral region and increasing ankle dorsiflexion, as demonstrated by Gross et al.[14]. However, the effectiveness of foot orthoses in treating cavus foot is still controversial, with some studies showing benefits and others not. Future research should focus on developing more effective therapeutic interventions to correct the biomechanical changes of the cavovarus foot and reduce the risk of injuries.

Neuromotor pathologies in cavovarus foot: unveiling the influence of Charcot-Marie-Tooth disease

The investigation of underlying neuromotor pathologies is critical in diagnosing cavovarus foot, especially in cases of atypical progression or suggestive family history. Among the various neuromotor conditions that may contribute to the development of this complex deformity, CMT disease stands out as a prevalent etiology, demanding an in-depth analysis of its mechanisms of action[2] (Table 2).

Charcot-Marie-Tooth disease, a heterogeneous group of hereditary neuropathies, exerts its impact on the cavovarus foot through a cascade of events that begin with the dysfunction of peripheral nerves. This neuropathy affects both motor and sensory nerves. The direct consequence of this dysfunction is the progressive degeneration of axons and myelin, essential structures for the efficient conduction of nerve impulses[15].

The degeneration of motor nerves leads to muscle weakness and atrophy, selectively affecting the intrinsic muscles of the foot and the leg. This selective weakness results in a characteristic muscle imbalance. In the cavovarus foot associated with CMT, a weakening of the tibialis anterior and peroneus brevis muscles is typically observed, while the tibialis posterior and peroneus longus muscles maintain their relative strength. This muscle imbalance is a key factor in the pathogenesis of a high-arched foot, as the unbalanced muscle forces act on the bone and joint structures of the foot, leading to progressive deformity[16].

The characteristic of CMT muscle imbalance contributes to the development of high-arched foot through several mechanisms such as the increase of the medial longitudinal arch by the weakness of the tibialis anterior muscle, responsible for dorsiflexion and inversion of the foot, which leads the tibialis posterior muscle to remain shortened and more potent contributing to the elevation of the medial longitudinal arch[16]. The weakness of the peroneus brevis muscle allows the inverting muscles, such as the tibialis posterior, to tilt the calcaneus medially, resulting in a hindfoot varus, favoring the mechanical overload on the lateral rays and base of the

Table 2. Cavovarus foot causes

Neuromuscular	Traumatic
Charcot-Marie-Tooth Disease	Crush injury
Poliomyelitis	Post-burn contracture
Friedreich's ataxia	Malunion of talus neck fracture
Traumatic brain injury	Peroneal nerve injury
Spina bifida	
Syringomyelia	**Congenital**
Terminal filum lipoma	Congenital talipes equinovarus
Tethered cord syndrome	Tarsal coalition
Cerebral palsy	
Spinal cord tumor	**Idiopathic**
Stroke	
Amyotrophic lateral sclerosis	
Huntington's chorea	
Guillain-Barré syndrome	
Peripheral neuropathy	

fifth metatarsal[16]. The imbalance between the intrinsic and extrinsic muscles of the toes, caused by the weakness of the intrinsic muscles, leads to flexion of the interphalangeal joints and extension of the metatarsophalangeal joint, resulting in claw toe deformities[16] (Table 3).

In addition to muscle imbalance, sensory neuropathy also plays an important role in the pathogenesis of cavovarus foot associated with CMT. The loss of protective sensation in the feet makes patients more susceptible to injuries and ulcers, especially in areas of increased pressure due to deformity. The lack of proprioception contributes to instability and increases the risk of sprains and falls[17].

Conservative treatment: an approach centered on muscle balance

The conservative treatment of cavovarus foot plays a crucial role in relieving symptoms and preventing the progression of the deformity[1]. Clinical reasoning continues with the goal of re-establishing the best possible muscle balance. Conservative treatment aims to optimize foot function, considering the influence of neuromotor dysfunction and the multifactorial etiology of the condition[4].

Conservative interventions aim to correct or minimize biomechanical and neuromotor imbalances. Physical therapy, with muscle strengthening and stretching exercises, aims to optimize the function of the intrinsic muscles of the foot and improve the flexibility of shortened structures[3]. The use of custom orthoses and insoles is essential to redistribute plantar pressures, provide support to the medial longitudinal arch, and improve hindfoot stability[1]. The choice of orthosis should be individualized, and it is essential to assess the flexibility of deformity so that the chosen orthosis can change the mechanics and rebalance the deformities resulting from the deviations and muscle imbalances identified[3]. In patients with CMT, footwear adaptation and the use of assistive devices may be necessary to protect the foot and minimize the risk of injuries resulting from the loss of protective sensation[2].

Conservative treatment offers a valuable approach to control symptoms and improve the quality of life of patients with cavovarus foot. Clinical reasoning centered on muscle balance directs the choice of the most appropriate interventions for each patient[4]. The decision to proceed to surgical treatment should be based on the failure of conservative measures to achieve therapeutic goals, such as improving pain, function, and stability of the foot[5]. Ultimately, the success of high-arched foot treatment lies in individualizing the approach, intending to create a plantigrade, mobile, stable, and pain-free foot[1].

Table 3. Correlation between deformities and muscle imbalances in cavovarus foot

Deformity	Weakness	Predominance
Increased medial Longitudinal arch	• Anterior tibial muscle	• Posterior tibial muscle (maintaining relative strength)
Hindfoot varus	• Peroneus brevis muscle	• Posterior tibial muscle • Peroneus longus muscle
Claw toe	• Intrinsic muscles (e.g., lumbricals, interossei)	• Extrinsic extensors and flexors

Surgical treatment

Surgical treatment of cavovarus foot should be carefully individualized, although certain basic principles apply to all cases. Respecting the biomechanical and etiological complexity is a sine qua non condition for a good outcome[18]. The pillars of surgical planning are meticulous analysis of stiffness, muscle imbalances, and plantar weight-bearing distribution.

Generally, the surgical sequence follows a functional principle: release of soft tissues, hindfoot correction, adjustments in the midfoot, and, when necessary, realignment of the forefoot. The ultimate goal—the "holy grail"—is not simple radiographic normalization, often unattainable, but obtaining a plantigrade, stable, and pain-free foot, capable of sustaining a functional gait and preserving the maximum joint mobility of the lower limbs[19] (Table 4).

Soft-tissue release - a primordial part

It is essential to perform an adequate release of soft tissues before correcting structural deformities. In most cases of long-standing cavovarus foot, shortening of the Achilles tendon and contraction of the medial and plantar tissues may occur. Not recognizing and addressing these changes is a common failure in the surgical strategy. In these cases, surgery should be initiated by releasing the Achilles tendon or gastrocnemius to correct the posterior variation mechanism and release the calcaneus. Percutaneous triple hemisection or open Z-plasty of the Achilles tendon and gastrocnemius recession can be performed selectively, according to the result of the Silfverskiöld test[3].

Next, attention should be directed to the persistent contracture of the plantar fascia, which results in shortening and stiffness of the foot. Usually, the plantar fascia exerts greater force on the first metatarsal in the midfoot region. Releasing it in this region may be more effective in improving bone positioning. The scissors are carefully introduced, without cutting movement, until the medial and lateral bands are completely released[1]. In more severe cases, where there is marked cavo-adducto-varus, it may also be necessary to release the fascia of the abductor hallucis tendon. Special attention should be paid to the plantar neurovascular bundle, which runs deep to the latter. In certain more rigid deformities, release of the fascia may not be sufficient, requiring complete detachment of the intrinsic muscles from their insertion in the calcaneus, as part of the correction strategy and as a facilitator for a subsequent calcaneal osteotomy.

Finally, the surgeon will need to analyze the possible sources of medial contractures, including the spring ligament, the flexor tendons, and the midfoot joints. Only then will the surgeon be able to determine which osteotomies should or should not be performed.

Balancing deforming forces - the role of tendon transfers

Rebalancing muscle forces is an essential part of surgical reconstruction in cavovarus foot, especially in patients with established neuromuscular etiology, where dynamic imbalances frequently sustain and recur the deformity. In these cases, simple structural correction is not sufficient; it is necessary to redirect force vectors to preserve the alignment obtained and avoid recurrences[20].

The choice of tendon transfers should respect the present imbalance pattern, established after meticulous motor testing.

Table 4. Surgical treatment options for cavovarus foot

Choice of surgical methods	
Soft-tissue release	
Contracture of the plantar fascia	Open or percutaneous plantar fasciotomy
Overpull of the intrinsic muscle	Steindler stripping
Ankle varus deformity	Lateral ankle ligament reconstruction
	Deltoid ligament release
Ankle equinus deformity	Gastrocnemius recession
	Achilles tendon lengthening
Severe rigid deformity	Combined with other tendon release
Bony reconstruction	
Forefoot deformity	
The first tarsometatarsal equinus	First metatarsal dorsiflexion osteotomy
The multiple metatarsals equinus	Jahss osteotomy
Midfoot deformity	
The apex at the naviculo joint or cuneiforms	Cole/Japas/Akron/Myerson osteotomy*
	Ilizarov external fixation
Hindfoot deformity	
Non-reducible mild heel varus	Dwyer osteotomy
Non-reducible severe heel varus	Z-shaped osteotomy
Mixed deformity	
Rigid deformity with osteoarthritis	Double or Triple arthrodesis
	Naviculo-cuneiform arthrodesis
Soft-tissue Balancing	
Weakness of the peroneus brevis	Peroneus longus to brevis transfer
Overpower of the posterior tibial tendon	Posterior tibial tendon transfer
Claw-toes	Jones procedure
	Hibbs procedure

The tendon to be transferred must have a strength grade of 4 or 5. When there is dominance of the tibialis posterior, its partial or total transfer to the dorsolateral region, such as the dorsum of the foot or lateral cuneiform, can restore the dorsiflexion symmetry. In cases of excessive action of the peroneus longus, responsible for accentuating plantar flexion of the first ray, its transfer to the peroneus brevis (with proper tensioning of both) helps to contain the plantar inclination of the forefoot and reduce varus[21].

The transfer of the tibialis anterior to a more lateral position may be indicated when there is asymmetric and dynamic dorsiflexion in gait, while the extensor digitorum longus can be repositioned to stabilize the hindfoot[22]. Other transfers can be performed depending on each case, such as the flexor digitorum longus or hallucis longus to the peroneus brevis (or base of the fifth metatarsal), and the extensor digitorum longus to the tibialis anterior (Figure 1).

Generally, the logic behind the transfers is not only compensatory, but preventive: by neutralizing deforming forces, a more balanced, lasting, and functional biomechanical environment is promoted. Ultimately, these strategies are fundamental to achieving not only anatomical correction but functional integrity of the foot over time.

Osteotomies or arthrodesis - the difficult decision in the "holy grail" of the cavovarus foot

The decision between performing osteotomy or arthrodesis when treating cavovarus foot requires careful evaluation of the flexibility and location of the apex of the deformity. Although tests such as the Coleman block are widely used to estimate the flexibility of the hindfoot (subtalar), their effectiveness in predicting adequate surgical correction is limited. In a series with 172 patients undergoing only osteotomies and tendon transfers, without arthrodesis, only 38% had satisfactory radiographic correction, which led the authors to question the isolated use of this test as a guide for decision-making[20]. Often, the best way to assess this flexibility is by manipulating the subtalar in varus-valgus, with the foot in physiological plantar flexion. The influence of this movement on the position of the forefoot is then appreciated. Generally, the more mobile the subtalar, the more the forefoot will be "equinized" with the hindfoot valgus.

Regarding the location of the apex of the deformity, it is common to perform extensor osteotomy of the first metatarsal, for example. Such osteotomy is convenient in subtle cases of high-arched foot, especially in the initial evolution of cases called forefoot-driven hindfoot varus, that is, cases in which the matrix deformity is in the forefoot and a globally flexible foot. Except for this situation, the apex of the deformity is always proximal, whether in the first tarsometatarsal joint, in the cuneiform, in the naviculo-cuneiform, or the talonavicular[23].

In mild and flexible deformities, with easily correctable subtalar and minimal supination of the midfoot, joint-preserving procedures are usually chosen. Especially if there is no adducto-varus deformity of the forefoot. This includes osteotomies of the calcaneus and first metatarsal, release of the plantar fascia, and tendon transfers, such as peroneus longus to brevis[24]. However, even in these cases, if the apex of the deformity is located more proximally—such as in the tarsometatarsal, naviculo-cuneiform, or talonavicular joint—, a realignment directly at this level may be necessary, avoiding technically distal osteotomies outside the core.

Moderate deformity, in turn, is marked by accentuated cavus and supination in the midfoot and signs of overload on the lateral border of the foot. Invariably, there is a rotation in the midfoot, which is usually more accentuated than the hindfoot varus. In these cases, the osteotomies used for mild deformities rarely manage to adequately correct the rotation of the midfoot or the persistent hindfoot varus. Thus, midfoot osteotomy-arthrodesis, performed at the apex of the deformity, becomes the key treatment. The procedure usually involves arthrodesis of the naviculo-cuneiform joint and osteotomy of the cuneiforms, with removal of a dorsomedial wedge and manipulation of the cuboid to correct supination[25]. It is important to assess the need for cuboid osteotomy because often the stiffness in the lateral column prevents adequate derotation, even if a reasonable extension is achieved in the medial and intermediate columns.

The same reasoning is verified in sub-corrected cases, in which the medial cuneiform-ground and fifth metatarsal-ground relationship remains unchanged even after certain procedures. To achieve this correction, it is important to remove a dorsal-based wedge towards the cuneiforms, tapering laterally to the cuboid, a region where no bone segment is removed. Regarding the hindfoot varus, often the combination of subtalar arthrodesis with valgus calcaneal osteotomy may be necessary to avoid undercorrections (Figure 2).

Therefore, the choice for arthrodesis is not only linked to the absolute stiffness of the foot but also to the location and complexity of the apex of the deformity. The surgical approach should aim three-dimensional realignment, with derotations that are intraosseous or intra-articular, avoiding compensations that result in residual deformities, such as persistence of subtalar varus or overload on the fifth metatarsal.

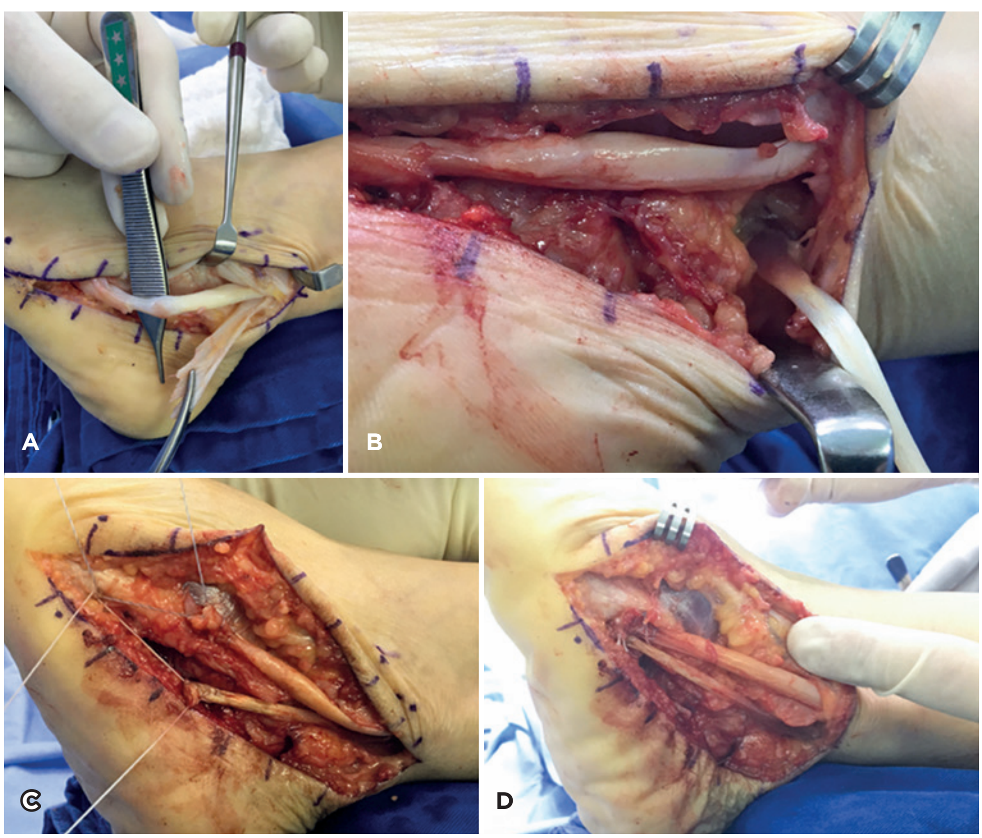

Figure 1. Example of tendon transfers. (A) An extensive peroneal tendon injury is seen. (B) The peroneus longus tendon is redirected to the peroneus brevis, and the flexor hallucis longus tendon is transferred laterally, posterior to the tibia/fibula. (C) Peroneus longus and flexor hallucis longus tendons are repaired and tensioned. (D) The peroneus longus is sutured to the remnant stump of the peroneus brevis, and the flexor hallucis longus is reinserted into the base of the fifth metatarsal.

Minimally invasive techniques have gained prominence in reconstructing the cavovarus foot, allowing structural corrections with less aggression to the soft tissues. On one hand, it seems attractive; at the same time, dispensing with soft tissue procedures can incur greater risks of recurrence[26]. Therefore, more robust studies are still lacking to determine which would be the best indications for this type of approach.

The lesson learned from Charcot-Marie-Tooth in cavovarus foot

The surgical approach developed for cavovarus feet of neuromuscular origin, as in patients with CMT, has brought valuable contributions to treating cavovarus feet of other etiologies. The main lesson is the need for a dynamic algorithm, which respects the sequence of soft tissue release, intraoperative evaluation, and progressive surgical decisions, adjusted according to the anatomical response in real time[27].

In CMT, surgical reconstruction aims at three fundamental objectives: (1) restore a plantigrade foot, (2) stabilize the hindfoot, and (3) recover active ankle dorsiflexion. This triad can also guide complex surgeries of idiopathic or post-traumatic cavovarus feet, even in the absence of diagnosed neuropathy.

Soft tissue release can be initiated by lengthening the calcaneal tendon, which is often shortened and vectorially contributes to hindfoot varus. Next, a medial release of the midfoot, centered on the talonavicular joint, is considered essential to correct supination and adduction of the midfoot and enable adequate plantar support. This type of release, including the release of the spring ligament and the tibialis posterior tendon, should be considered in rigid cavovarus feet, even if non-neuromuscular[28]. In cases where ankle dorsiflexion is extremely weak, the flexor digitorum longus or hallucis longus tendon can also be released and used for transfer, together with the tibialis posterior, to the dorsum of the midfoot. Medial release of the subtalar joint can be performed in cases of greater rigidity, taking care not to overcorrect in hindfoot valgus.

Figure 2. Example of satisfactory correction using a Z-shaped calcaneal osteotomy with wedge resection, along with a dorsal closing wedge osteotomy of the first metatarsal and tendon transfer of the peroneus longus to the base of the fifth metatarsal. Despite the first metatarsal osteotomy being performed away from the apex of the deformity, good correction was achieved.

Calcaneal osteotomy is another critical point. In CMT, the “C” morphology of the calcaneus demands combined osteotomies, lateral closing with translation, and valgus rotation. Although Z-shaped osteotomies of the calcaneus are an option, the “triple Dwyer” seems to act more on the apex of the calcaneal deformity.

The forefoot approach completes the sequence with the elevation of the first ray, usually by dorsal closing osteotomy. Extensor osteotomy of other metatarsals may also be necessary or even be done through the cuneiforms. The perception of the change in positioning of the forefoot throughout the surgery highlights the importance of not anticipating corrections before proximal corrections[29]. Only after all osteotomies have been fixed, should the surgeon finalize the tendon transfers, such as the tibialis posterior to the medial or intermediate cuneiform. Transferring the same to the lateral can cause excessive midfoot pronation if not well indicated. If the flexor digitorum longus (or hallucis longus) was released during the first surgical time, this can be used as a corrective force for the weakness of ankle dorsiflexion. Or even, transferred to the fibularis (or base of the fifth metatarsal) in the case of combined injury of these tendons, compromising eversion (Figure 3).

The surgical treatment of cavovarus foot associated with CMT offers a practical lesson on the principle of surgical sequence, extensive tissue release before bone corrections, and functional evaluation of the remaining muscles. These teachings become extremely valuable even in cases where the etiology of cavovarus foot is not neurological but presents comparable rigidity and complex deformity.

Toe deformities in cavovarus foot - the surgical rationale

Deformities of the lesser toes in the context of a high-arched foot represent manifestations frequently related to neurological causes, resulting from complex muscle imbalances between intrinsic and extrinsic structures of the forefoot. Persistent hyperextension of the metatarsophalangeal joint combined with flexion of the proximal and distal interphalangeal joints configures the classic claw pattern, common in neuromuscular dysfunctions, but also observed in idiopathic or biomechanically induced forms. Pathogenesis involves factors such as shortening of the plantar fascia, failure of the reverse windlass mechanism, and progressive deterioration of the plantar plate, often aggravated by metatarsal imbalances, inadequate footwear, or concomitant hallux deformities[30].

The surgical approach to these deformities requires careful evaluation of reducibility, stability of the metatarsophalangeal, and involvement of the interphalangeal. In flexible deformities, tendon release techniques and arthrolysis are often effective. Percutaneous or open tenotomy of the extensor hallucis longus and brevis and flexor digitorum longus and brevis allows rebalancing of digital vector forces, and can be complemented by capsular arthrolysis. Tendon transfers, such as Girdlestone-Taylor (flexor digitorum longus to the dorsum of the proximal phalanx), act not only as anatomical correction but also as a functional tool, reestablishing the plantar moment in the stance gait phases. These transfers show good results both in toes with purely sagittal deformities and in cases with an axial component, such as the "crossover toe"[31].

In structured or rigid deformities, correction requires bone procedures and fusions. Arthrodesis of the proximal interphalangeal with intramedullary devices or Kirschner wires provides lasting alignment, often associated with joint excision in cases of advanced degeneration. In fixed mallet toes, the distal interphalangeal can be stabilized with wires or implants, and, when there is a risk of recurrent ulcers, terminalization (partial amputation) is considered. Metatarsal shortening osteotomy, notably Weil's, plays a central role in the treatment of metatarsophalangeal instability, both by restoring the metatarsal parabola and by facilitating joint reduction. Although effective, it is associated with complications such as floating toes, requiring attention in case selection and rehabilitation[30].

Minimally invasive approaches have been gaining ground, especially in tenotomies and distal osteotomies, with less tissue morbidity and reduced recovery time. However, the rate of complications such as residual edema and stiffness

Figure 3. Sequence of images in a case of Charcot-Marie-Tooth disease. This patient had a flexible deformity despite evident osteoarthritis in the tarsal joints. A particular feature was the severe loss of strength, especially in ankle dorsiflexion, resembling a flaccid paralysis. Classical osteotomies were chosen: first ray dorsal wedge osteotomy and triple Dwyer procedure (lateralization, elevation, and lateral wedge resection) of the calcaneus. Additionally, the peroneus longus was transferred to the base of the fifth metatarsal, and the posterior tibial tendon was transferred to the dorsum of the midfoot through the interosseous membrane. Due to the severe loss of ankle extensor strength, a tenosuspension of the peroneus brevis was performed, along with a tri-tendon anastomosis with the posterior tibial and anterior tibial tendons.

still demands critical evaluation and more studies. Regardless of the technique, there is a consensus that correction of proximal deformities (hindfoot and midfoot) should precede the treatment of the toes, as global biomechanical changes can directly influence digital alignment and function. A sequential, and eventually staged, approach, starting with the most proximal structures and progressing to the digital ones, allows a precise intraoperative reevaluation of residual deformities, optimizing functional and aesthetic results (Figures 4, 5, and 6).

Hallux in cavovarus foot - when the great toe enters the "holy grail"

Hallux claw deformity, also called hallux malleus, is a frequent manifestation in patients with cavovarus foot, especially when associated with neuromuscular diseases such as CMT. This condition is characterized by hyperextension of the metatarsophalangeal joint combined with flexion of the distal interphalangeal joint, resulting in plantar overload under the head of the first metatarsal and on the tip of the hallux, predisposing to pain, callosities, and ulcers, especially in patients with sensory neuropathy[32].

The main cause of the deformity is the muscle imbalance between the extrinsic muscles, notably the extensor hallucis longus, the flexor hallucis longus, and the peroneus longus, and the intrinsic muscles, which, by losing their stabilizing function on the metatarsophalangeal joint, allow competing flexion and extension forces to deform the axis of the toe. Although etiology may be idiopathic, the neurological form is the most common, with CMT being the main associated disease.

The Jones procedure is the surgical technique of choice for treating this deformity when there is sufficient flexibility and functional impairment. It consists of transferring the extensor hallucis longus— sectioned distally—through a transverse tunnel through the neck of the first metatarsal, where it is fixed under physiological tension. This gesture removes the deforming extensor force on the metatarsophalangeal and repositions the extensor hallucis longus vector to exert a stabilizing and dorsiflexor effect on the first ray. The procedure is rarely performed in isolation, being frequently associated with arthrodesis of the interphalangeal joint of the hallux, to avoid compensatory deformities such as mallet toe of the hallux[33].

In cases where the first metatarsal presents a fixed position in plantar flexion, the Jones procedure should be complemented by a dorsiflexion osteotomy of the first metatarsal, as isolated tendon transfer is not able to elevate the first ray due to the persistent force of the intact peroneus longus tendon. Additionally, the procedure can be integrated into broader corrections of the cavovarus foot, including hindfoot osteotomies, plantar fascia releases, and tendon transfers of dorsiflexors, as part of a multiplanar reconstruction (Figure 7).

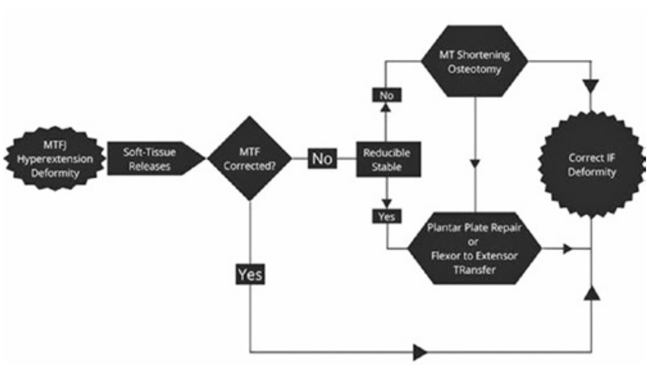

Figure 4. Algorithm for managing hyperextension deformity of the metatarsophalangeal joint. After correcting this deformity, any changes in the interphalangeal joints should be assessed and treated.

MTPJ: Metatarsophalangeal joint; IPJ: Interphalangeal joint; MT: Metatarsal.

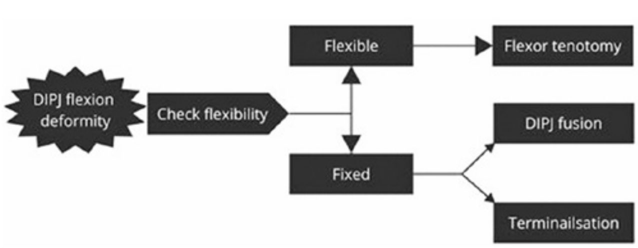

Figure 5. Algorithm for managing flexion deformities of the distal interphalangeal joint, as seen in mallet toe or as a component of claw toe.

DIPJ: Distal interphalangeal joint.

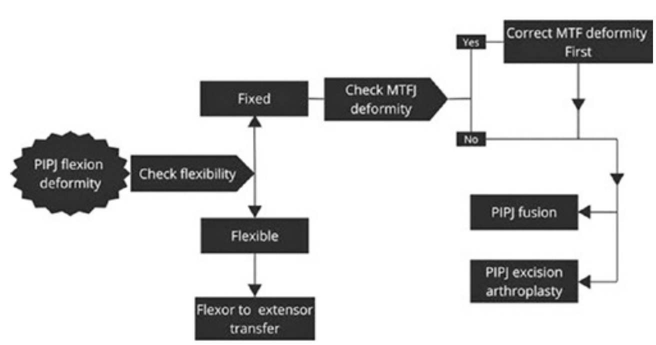

Figure 6. Algorithm for managing flexion deformities of the proximal interphalangeal joint, as in hammer or claw toe. In the presence of a fixed deformity, any associated changes in the metatarsophalangeal joint should be corrected first.

PIPJ: Proximal interphalangeal joint; MTPJ: Metatarsophalangeal joint.

Figure 7. Jones procedure for correction of hallux claw deformity. The extensor hallucis longus tendon is detached through the distal incision and reinserted proximally after being passed transversely across the neck of the first metatarsal.

Conclusion

The growing understanding of the influence of neuromotor dysfunction, especially Charcot-Marie-Tooth disease, redefines the diagnostic and therapeutic approach, requiring an in-depth analysis encompassing mechanical deformities, biomechanics, and underlying neuromotor pathologies. Accurate diagnosis is an important step in studying cavovarus foot for the ideal treatment. The identification of mechanical deformities allows delineating the morphological profile of the foot and guiding the understanding of the altered anatomy. Biomechanical analysis, in turn, reveals changes in the distribution of plantar pressures and the kinematics of the foot, providing valuable information about function and susceptibility to injuries. Investigation of underlying neuromotor pathologies, as in Charcot-Marie-Tooth, assumes a prominent role in the diagnostic evaluation, by generating a cascade of events that begin with the dysfunction of peripheral nerves, leading to muscle weakness and characteristic imbalance.

Analyzing all the complex variables that lead to cavovarus foot in an integrated way, the therapeutic options diversify from conservative approaches to surgical interventions. Physical therapy and the use of orthoses aim to optimize foot function, correcting or minimizing biomechanical and neuromotor imbalances. Surgical treatment, carefully individualized, aims to obtain a plantigrade, stable, and pain-free foot.

The search for developing a dynamic algorithm, which respects the sequence of soft tissue release, intraoperative evaluation, and progressive surgical decisions, adjusted according to the anatomical response in real time, emerges as a fundamental principle to be followed. This flowchart of reasoning and surgical decision-making about reducibility, stability of metatarsophalangeal, and involvement of interphalangeal, combined with tendon release techniques, arthrodesis, and osteotomy, allows restoring alignment and digital function.

The search for the “holy grail” in treating cavovarus foot requires an individualized and multifaceted approach, which considers the influence of neuromotor dysfunction and the complex etiology of deformity. By adopting clinical reasoning centered on muscle balance and by applying the available techniques and tools judiciously, we can aspire to a plantigrade, mobile, stable, and pain-free foot, capable of sustaining a functional gait and preserving maximum joint mobility. Despite the challenges inherent in this journey, the growing understanding of the biomechanics and pathophysiology of cavovarus foot allows us to glimpse a promising future, with new therapeutic approaches and increasingly satisfactory results.

Authors’ contributions: Each author contributed individually and significantly to the development of this article: LFF *conceived and planned the activities that led to the study; RCV, and FLM interpreted the results of the study, participated in the review process. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Review

Neglected Achilles tendon ruptures: literature review

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Abstract

Objective: Review the literature on the current treatment of neglected Achilles tendon ruptures, their results, and potential complications.

Methods: Bibliographic review on the state of the art in national and international databases. Articles published in indexed journals between 1991 and 2022 that addressed the treatment of Achilles tendon ruptures with more than four weeks of evolution were selected; however, only articles with less than 22 years of publication (2000-2022) were analyzed.

Results: Surgical treatment is well-established in patients with significant functional demands. The various surgical techniques described in the literature and currently used have similar success rates and complications, especially regarding patient satisfaction, functional results, anthropometric measurements, and return to work and sports activities.

Conclusion: Several techniques can be used to treat neglected Achilles tendon ruptures. When choosing the most appropriate technique, gap size, patient characteristics, and surgeon experience should be considered.

Level of evidence I; Type of study; Evaluation of results.

Keywords: Achilles tendon; Rupture; Surgical procedures, operative.

Introduction

Achilles tendon rupture is the most common tendon injury of the lower limb. This injury is particularly significant due to the tendon's crucial role in transferring, storing, and releasing energy during locomotion[(1)].

Its prevalence is estimated at 0.2% of the general population and increases in individuals in the fourth decade of life[(2)]. Achilles tendon ruptures have increased in the last decade due to the growing interest in recreational physical activities, especially by patients above this age group[(3)]. Approximately one in four Achilles tendon ruptures will be neglected by patients and physicians at first, either due to the nature of the trauma, minor pain, or maintenance of plantar flexion movement[(4)].

A delay of more than four weeks between injury and diagnosis is defined as a neglected or chronic Achilles tendon rupture. Neglected injuries result in loss of plantar flexion associated with edema, pain, and limited ankle movement. Surgically, they differ from acute ruptures due to the difficulty of apposition of the stumps for primary end-to-end suture with plantar flexion of the ankle[(5)].

These injuries can heal spontaneously due to the abundant fibrous tissue in the gap. However, the functional result is not ideal because, due to the associated contraction of the triceps surae, there is insufficient healing from a functional point of view, which sometimes generates weakness in performing plantar flexion with weight-bearing.

The objective of this study is to review the literature on the current treatment of neglected Achilles tendon ruptures, their results, and potential complications.

Methods

This systematic review was developed following the recommendations of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol to ensure transparency, methodological rigor, and reproducibility in the search, selection, and analysis of studies.

Study performed at the Hospital IFOR – Rede D'Or São Luiz, São Bernardo do Campo - SP, Brazil.

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Sources of information and search strategy

Our study was conducted as a systematic review of scientific articles indexed in the PubMed, Bireme, SciELO, and ScienceDirect databases. The search strategy included the terms: "neglected Achilles tendon rupture," "chronic Achilles," "delayed diagnosis Achilles tendon rupture," and "tendon transfers."

Eligibility criteria

The inclusion criteria were studies that addressed skeletally mature patients over 18 years old, studies that demonstrated results of managing supervised chronic Achilles tendon ruptures, and articles that presented at least the abstract in English.

Exclusion criteria

The exclusion criteria were studies that did not contain the mentioned terms and keywords, articles published before 2000 or after 2022, articles that were not published in indexed journals, studies with less than ten patients in the analysis, studies involving patients with associated injuries, other than Achilles tendon rupture, study involving patients with acute Achilles tendon ruptures, and animal studies.

The selection process

The selection of studies was performed in three stages: (1) Initial screening based on article titles and abstracts, (2) Evaluation of the full texts to confirm the eligibility criteria, and (3) Detailed analysis of the results obtained in each article to extract the relevant data.

All articles were independently analyzed by two reviewers. In cases of disagreements, a consensus was reached through discussion among all authors of the review.

Data extraction and synthesis

Extracted data included demographic characteristics of patients, details of the interventions, and clinical and functional outcomes reported.

Data synthesis was performed qualitatively, describing the methods used in the studies and their final outcomes.

Methodological quality assessment

The methodological quality of the studies was evaluated based on previously defined criteria, ensuring the validity and reliability of the results included in the review.

Results

Four hundred and ninety-one articles were found, most dealing with surgical descriptions, case reports, or case series. No large cohort studies or meta-analyses were found. After applying the inclusion and exclusion criteria, 25 articles were selected and analyzed. Figure 1 details the process of identifying eligible studies.

The selected studies, the repair method used in each of them, and the complications and results are briefly described in Table 1[1,6-29].

Techniques used to treat neglected Achilles tendon ruptures included direct repairs, allografts, transfers of the flexor hallucis longus, flexor digitorum longus or peroneus brevis tendon, graft with knee flexors, V-Y advancements, minimally invasive techniques, use of Achilles tendon flaps. There was no standardization in the outcomes analyzed in the included studies. The variables analyzed in the studies were calf circumference, muscle contraction strength scales, time to return to work and sports activities, pain scales such as the visual analog scale (VAS), and validated functional scores. The American Orthopaedic Foot and Ankle Society (AOFAS) score was also used to assess injuries in different regions of the foot.

Discussion

The Achilles tendon is the strongest in the human body, and intrinsic and extrinsic factors can influence its rupture. Genetic predisposition, hypovascularization, and repetitive microtrauma are the main causes described in the literature[30]. These injuries are diagnosed based on anamnesis, physical examination, and, more recently, ultrasound and magnetic resonance imaging findings.

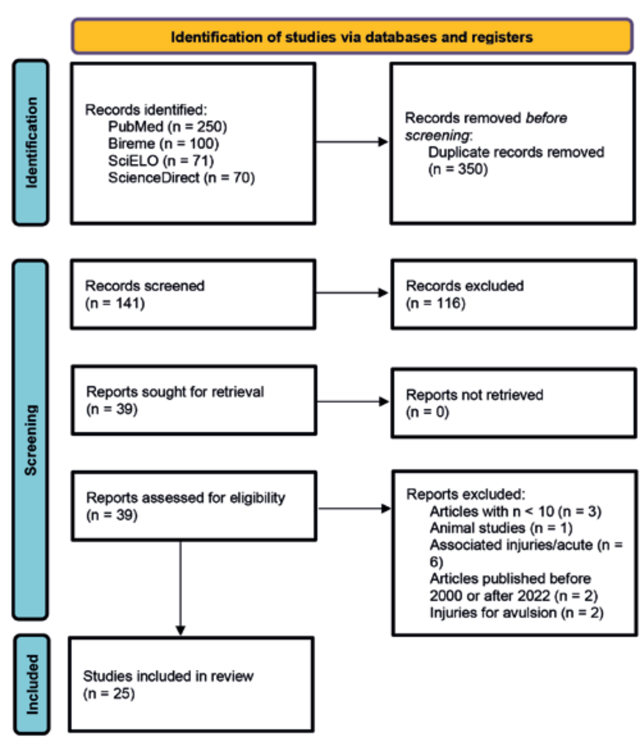

Figure 1. Eligible studies identification process.

Table 1. Methods of repair and results of included studies

Author	Methods	Results	Re-rupture	Complications
Lin et al., 2019[1] (Retrospective study)	V-Y tendon plasty (20)	Mean follow-up of 32.8 months Mean injury-to-surgery was 20.4 weeks Mean operative gap was 5 cm Mean preoperative AOFAS score was 59.25 ± 12.28 and postoperative was 96.55 ± 3.75 Mean preoperative ATRS score was 39.55 ± 14.21 and postoperative was 94.05 ± 4.89 No patient was limited when walking on uneven surfaces and walking quickly up stairs	No	1 superficial infection treated with antibiotics and debridement
Wilcox et al., 2000[6] (Retrospective study)	Flexor hallucis longus (20) – two incisions	Mean AOFAS of 86 90% of patients with AOFAS > 70 No significant difference in the SF-36 compared to USA norms except for physical function (significantly lower scores) Cybex strength testing: gain of 3% of dorsiflexion strength and loss of 7% of plantarflexion strength	No	Small loss of calf circumference
Pintore et al., 2001[7] (Prospective study)	Peroneus brevis tendon (22)	No patient presented poor functional results (all performed single-leg heel rises five times) Reduction of peak torque (newtons per meter), total work (joules), and average power (watts)	Not informed	Loss of calf circumference (not significant) Superficial operative infection in two patients Hypertrophic scar in one patient Deep vein thrombosis in one patient (diabetic)
Jennings and Sefton 2002[8] (Retrospective study)	Polyester tape (16)	Median time of partial weight-bearing: 17 days Median time of full weight-bearing: 5.9 weeks Median times to return to work and driving, and sports Tempo médio para retorno ao trabalho, dirigir e esportes: 7, 8, 6, and 18 weeks, respectively Only two patients had increased dorsiflexion compared with the uninjured leg Mean isometric power of the operated leg (238.7 N) vs. uninjured leg (281 N) ($p > 0.05$) Mean circunference of the operated leg of 32.1 cm vs. unoperated leg 36.6 ($p < 0.05$) Reduction of Tegner activity score from 2.7 to 1.8 ($p < 0.05$)	No	One patient needed further surgery for excision of the tape One patient had persistent numbness in the distribution of the sural nerve Three patients had superficial infections
Suttinark et al., 2009[9] (Retrospective study)	Flexor hallucis longus (12)	Mean follow-up time of 22.5 months Improved mean AOFAS from 54.6 to 92.9	Not informed	Slightly decrease of strength in flexion of the first metatarsophalangeal
Park et al., 2012[10] (Retrospective study)	V-Y advancement, gastrocnemius fascial turn-down flap, flexor hallucis longus tendon transfer, or Achilles tendon allograft (12).	Follow-up of 36.2 months AOFAS: 68.7 (preoperative) to 98 (postoperative) VAS: 6.5 (preoperative) to 0.17 (postoperative) All patients performed 10 single-leg heel rises on the operated leg ROM: was equal to that of the opposite side in nine patients, and dorsiflexion was smaller by < 10º in three patients Seven patients rated as excellent, four as good, and one as fair	No	None
Maffulli et al., 2010[11] (Prospective study)	Peroneus brevis tendon transfer through two paramidline incisions (32)	Mean final ATRS of 92.5 Loss of muscle strength and calf circumference compared to nonoperated side The majority of the patients were satisfied with the results Six patients were classified as excellent, and 24 as good	Not informed	Four patients had superficial infections in at least one operative wound Two patients had a hypertrophic scar in the area of the Achilles tendon

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Table 1. Methods of repair and results of included studies

Author	Methods	Results	Re-rupture	Complications
Maffulli and Leadbetter, 2005[12] (Prospective study)	Free gracilis tendon graft	Follow-up of two years 19 patients with no pain and two patients with mild pain (postoperative) 12 patients with no limitation for recreational activities and 9 with limitations 19 patients with restrictions or mild restrictions to footwear and two with moderate restrictions 19 patients were satisfied, and two had minor reservations Overall results: two excellent, 15 good, and four fair Decrease in calf circumference compared to the uninjured leg (mean): 39.2 vs. 40.9	Not informed	Five patients had superficial wound infections
Mao et al., 2015[13] (Retrospective study)	Flexor hallucis longus transfer associated with gastrocnemius fascial turn-down flap and plantaris tendon	Mean AOFAS from 64.4 in the operative to 94.3 in the postoperative ROM evolved closer to the nonoperative side with a mean of 12º (5º–15º) of dorsiflexion and 40.5º (35º –50º) of plantarflexion	Not informed	Not informed
Maffulli et al., 2017[14] (Review article)	Semitendinosus (21) – gap ≥ 6 cm Peroneus brevis tendon (20) Flexor hallucis longus (21)	All patients showed significant improvements in the operative ($p < 0.001$) with no difference between groups Peroneus brevis tendon transfer had a slower return to sports	Not informed	None
Vega et al., 2018[15] (Retrospective study)	Endoscopic flexor hallucis longus transfer (22)	Mean AOFAS score increased from 55 to 91 All patients returned to their daily activities without difficulties, and only one patient reported mild pain No patients reported complaints of great toe flexion strength	No	1 calcaneal bone avulsion
Pendse et al., 2019[16] (Retrospective study)	Flexor hallucis longus with a single incision (17)	Mean follow-up of 27 months Mean AOFAS increased from 57.47 to 96.71 Mean calf girth atrophy was 1.53 cm No significant difference in the range of ankle movement	No	All patients had decreased plantar flexion strength in the great toe One patient had superficial cellulitis successfully managed with oral antibiotic
Abubeih et al., 2018[17] (Prospective study)	Flexor hallucis longus with a single incision (21)	Mean follow-up of 15 months Mean AOFAS increased from 57.4 ± 10.3 to 95.3 ± 4.4 At the end of the study, 16 patients (76%) were able to lift the heel in unipodal support All patients showed weakness in flexion of the hallux interphalangeal joint, but no functional impairment	No	One patient had superficial cellulitis successfully managed with oral antibiotic
Alhaug et al., 2019[18] (Retrospective study)	Flexor hallucis longus (21)	Median maximal concentric strength was equal,1300 vs 1336 W, comparing affected with unaffected side Mean heel rise was 5.5 for the affected side and 26.5 for the unaffected leg Mean work energy was 219J for the affected side and 2398J for the unaffected leg Mean ROM was 7.35 cm for the affected side and 13.7 cm for the unaffected leg Mean AOFAS was 87and the VISA-A was 81	One patient	Five patients had infections, three being deep infections and one patient required plastic surgery Two had prolonged healing Two had claw toes Three had poor sensibility in the sural nerve area

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Table 1. Methods of repair and results of included studies

Author	Methods	Results	Re-rupture	Complications
Bai et al., 2019[19] (Retrospective cohort)	Comparison of free hamstring graft (15) and gastrocnemius turn flap (11)	Three months: higher degree of ankle dorsiflexion in the hamstring graft group ($p = 0.004$), with no significant differences in ankle function Six months: no significant differences in dorsiflexion and ankle function in both groups 12 months: no significant differences in dorsiflexion, ankle function, and AOFAS score in both groups	No	One patient had a saphenous nerve injury in the hamstring graft group Two patients had impaired wound healing in the gastrocnemius turn flap group One patient had deep vein thrombosis in the gastrocnemius turn flap group
Guclu et al., 2016[20] (Comparative retrospective study)	V-Y tendon plasty with fascia turndown (17) Follow-up of 16 years	Mean time until surgery was seven months Mean gap was 6 cm Mean AOFAS score was 64 in the preoperative and 95 in the postoperative The defect size did not affect the AOFAS score but affected the peak torque The gap size, time to surgery, and calf atrophy had an adverse effect on the muscle strength, but did not affect the postoperative outcomes	No	Two superficial infections
Koh et al., 2019[21] (Comparative retrospective study)	Flexor hallucis longus (29) vs. turndown flaps augmented with flexor hallucis longus (20)	In one year the VAS score was 0 for both groups Mean AOFAS score was 90 ± 11 for Flexor hallucis longus and 95 ± 10 turndown flaps augmented with flexor hallucis longus SF-36 showed improvement in the functional and physical scores Turndown flaps augmented with flexor hallucis longus had longer surgical time (100 ± 21min) vs. flexor hallucis longus (73 ± 23min)	No	Two cases of soft tissue complications (one stitch abscess and one wound dehiscence) in the turndown flaps augmented with flexor hallucis longus group
Lever et al, 2018[22] (Retrospective cohort study)	Transtendinous flexor hallucis longus transfer (20)	Mean follow-up of 73 months Mean ATRS score was 83 in the postoperative Mean AOFAS score was 94.3 in the postoperative Mean SF-12 score was 4.,8 in the physical component and 54.3 for the mental component The great toe strength was 40% weaker than the contralateral side The ankle plantarflexion strength was 24% weaker than the nonoperative side	No	Six 6 had wound problems, three superficial infections, one wound dehiscence, one slow scar healing, and one scar adhesion
Massoud et al., 2017[23] (Prospective – case series)	Lengthening of the proximal tendon stump (15)	All patients returned to the normal level of daily activities, no pain, tenderness, or stiffness at the ankle The calf circumference was equal among the 12 patients Three patients had calf atrophy Ankle motion was equal to the contralateral side	No	Three superficial infections One deep infection Two scar adhesion
Ofili et al., 2016[24] (Retrospective study)	Achilles tendon allograft (14)	Mean follow-up was 16.1 months Mean time to surgery was 6.9 months Mean defect size was Média 3.7 cm Bone graft was used in two cases All patients were able to perform a single-limb heel rise at 27 weeks Weight-bearing in normal shoe gear was achieved at a mean of 13.5 weeks	No	One delay union that was treated with calcaneal bone block

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Table 1. Methods of repair and results of included studies

Author	Methods	Results	Re-rupture	Complications
Ozan et al., 2017[25] (Retrospective study)	Lindholm method (8) vs. Vulpius method (7)	Mean follow-up of 19.6 months Mean time to surgery was 42 days Mean defect size was 4 cm Mean calf atrophy was 1.2 cm Mean time to return to daily activities was 3.2 months All patients were able to perform a single-limb heel rise at the end of follow-up	No	No
Ozer et al., 2018[26] (Prospective study)	Flexor hallucis longus (19)	Mean time to surgery was 36 days Mean AOFAS hindfoot score was 93.83 in the postoperative Mean AOFAS hallux score was 86.9 in the postoperative No significant difference was found in the balance performance No significant difference was found in the vertical and forward jump Less ankle dorsiflexion on the operated side was recorded compared with the nonoperated side ($p = 0.008$) Concentric/eccentric muscle strength between the operated and nonoperated side was similar ($p > 0.05$)	No	No
Seker et al., 2016[27] (Retrospective study)	Lindholm method (21)	Mean follow-up time of 145.3 months Mean calf circumference on the operated side was 36.2 cm and the nonoperated side was 37.2 cm, not significant ($p = 0.291$) Mean ankle range of motion on the operated side was 19º and the nonoperated side was 18º Mean time to return to daily activities was 11.1 weeks Mean AOFAS score was 98.5, and FADI was 98.9; VAS was 0	No	One superficial infection treated with antibiotics
Yasuda et al., 2016[28] (Retrospective study)	Scar tissue located between the tendon stumps (30)	Mean plantar flexion angle increased ($p = 0.0049$) Mean dorsiflexion angle decreased ($p = 0.009$) Mean calf circumference increased in the postoprative ($p = 0.0087$) All patients were able to perform a single-limb heel rise, except two patients Mean AOFAS score in the postoperative was 98.1 Mean ATRS score in the postoperative was 92.0	No	One delay scar healing
Song et al., 2020[29] (Retrospective – case series)	Semitendinosus allograft (34)	Mean follow-up of 53 months Functional and clinical scores had a significant increase 39.4% returned to previous sports activities All patients were able to stand on tiptoe of the single injured limb Mean AOFAS score in the postoperative was 100, ATRS was 99, VISA-A was 94, and Tegner was 4	No	Four patients complained of mild pain when the weather was colder or after a minimum of 30 min of sitting, walking, or jogging, which were alleviated by ultrasonic or microwave therapy, slight footwear modifications with heel cushions, and stretching

Achilles tendon ruptures not diagnosed in the acute phase, in which conservative treatment fails after four weeks, or chronic ruptures due to degeneration are considered neglected or chronic Achilles tendon ruptures. Clinically, these injuries rarely present palpable gaps due to the formation of local scar tissue[31]. However, with close clinical examination, the change in local tissue consistency can determine the rupture site. Other physical examination findings are dependent on the degree of healing. Patients may present a deficit of strength in plantar flexion, with a delay of the heel detachment phase in gait, which generates great discomfort. Patients are unable to stand or walk on tiptoes. Plantar flexion force can only be recovered with surgical treatment during this period.

Ultrasound is the imaging method with the highest availability and good accuracy for diagnosing Achilles tendon ruptures. Magnetic resonance imaging has recently become the gold standard method, but its little availability, especially in public health, and its high cost do not place it as the first choice[32].

The treatment of neglected Achilles tendon ruptures remains controversial since several surgical techniques have been described, and even conservative treatment can be indicated, especially in smoking patients with diabetes mellitus and in those with soft tissue complications.

Conservative treatment involves serial immobilizations with a gradual reduction of equinus at each visit. However, this approach is associated with prolonged immobilization and poorer functional outcomes, as fibrosis at the injury site can lead to shortening of the triceps surae, potentially causing functional impairment of ankle plantar flexion in the affected limb.

Surgical treatment has as its primary objective the restoration of function and strength of the triceps surae by restoring the adequate length-tension ratio. Primary anastomosis is the preferred approach in acute ruptures when stump apposition is feasible. This technique optimally restores tendon length before the injury, allowing for maximum isokinetic strength recovery.

Neglected ruptures are complicated by shortening and contracture of the gastrocnemius-soleus complex. Due to the difficulty in achieving stump apposition and performing a primary suture, various techniques have been developed to overcome these difficulties.

In this context, managing neglected Achilles tendon rupture has become challenging due to the diversity of available techniques and the lack of standardization in the analyzed outcomes. When choosing the most appropriate technique, gap size, patient characteristics, and surgeon experience should be considered.

Among the most used tendon transfer techniques, flexor hallucis longus transfer stands out for its proximity to the Achilles tendon, its similar force vector, and the vascular support provided to the rupture area. However, complications such as calf atrophy and loss of strength in the hallux flexion limit its use in some cases[13,16]. The nine studies that analyzed this technique[6,9,13,16-18,21,22,26] reported a mean postoperative AOFAS score of 92.53 (86–96.71). Major complications reported included calf atrophy, loss of strength in the first metatarsophalangeal joint, superficial infections, and problems with surgical wounds. Reconstruction with flexor hallucis longus performed endoscopically was described in a study[15], presenting satisfactory results, such as a return to daily activities in all patients evaluated.

Another well-established technique to repair these ruptures is the transfer of one of the peroneus muscles. The most used and best described in the literature is the peroneus brevis tendon transfer. The most used technique consists of two incisions, one on the fifth metatarsal base, to identify the short fibular tendon and one posterior, medial to the Achilles tendon. One variation uses only a longitudinal incision of approximately 12 cm, immediately lateral to the Achilles tendon[7], having been described in a study with five patients, who obtained improvement in plantar flexion, with minimal loss of range of motion and ability to return to pre-injury activity levels, with only one episode of occasional edema.

Pintore et al.[7] conducted a study on the transfer of the peroneus brevis tendon in 22 patients with neglected Achilles ruptures with a mean age of 41.3 years and 27 patients with acute Achilles ruptures with a mean age of 43.6 years. Patients were operated on by a single surgeon and evaluated postoperatively at six weeks and six months for satisfaction, complications, plantar flexion muscle strength, and calf circumference. They concluded that patients have good satisfaction after surgery but with loss of muscle strength and calf circumference and an increased incidence of complications when compared to the group of acute ruptures, such as superficial surgical wound infection in two patients, in addition to hypertrophic scarring and deep vein thrombosis in one patient each.

In our review, we also included the studies by Maffulli et al.[11,14] addressing peroneus brevis tendon transfer, in which good results are evidenced, such as a mean final Achilles tendon total rupture score of 92.5, and 30 of 32 patients with excellent or good results[11]. The complications described were superficial infection of at least one of the operative wounds and hypertrophic scar in the area of the operative wound of the Achilles tendon[11].

Subsequently, when comparing the technique above with semitendinosus graft and flexor hallucis longus transfer, the authors observed that patients submitted to peroneus brevis transfer had a slower return to sport[14].

For gaps greater than 6.0 cm, the semitendinosus graft transfer technique was used by Maffulli et al.[33], demonstrating efficacy similar to established techniques, such as flexor hallucis longus and peroneus brevis transfer.

In this context, studies advocating tendon stretching over transfer techniques argue that the difficulty in apposition and primary suture of the stumps is primarily due to the shortening of the triceps surae; the tendon stretching techniques that were developed fit. Such techniques do not require synthetic materials, such as the advancement of tendon flaps and V-Y advancements, and have been valued for their reduced cost, presenting comparable functional results.

The gastrocnemius aponeurosis or fascial flaps can also be used for reconstruction. In this procedure, the dissected flap of the proximal stump is advanced distally and sutured to the terminal stump. Seker et al.[27], using the Lindholm technique with 21 patients, found favorable functional results without sacrificing other healthy tissues and with only one superficial infection.

Using the same technique, Ozan et al.[25] demonstrated that all patients could perform single-leg heel rises at the end of the follow-up, although they presented a mean calf atrophy of 1.2 cm.

Park and Sung[10] performed a study in which they used multiple techniques, but with a total number of only 12 patients (V-Y advancements in one patient, V-Y advancements with flexor hallucis longus tendon transfer in one patient, gastrocnemius fascial turn-down flap in three patients, gastrocnemius fascial turn-down flap simultaneously performed with flexor hallucis longus tendon transfer for three patients, and V-Y advancements simultaneously performed with flexor hallucis longus tendon transfer and Achilles tendon allograft in two patients). The results were similar, but the patients were carefully selected according to the defect size. In their study, patients with defects < 5 cm performed V-Y advancements alone, and patients with defects greater than 10 cm performed surgery with allograft. Patients with intermediate defects were randomly allocated to the other techniques.

Allografts can also be used for Achilles tendon repair. In a study, Ofili et al.[24] found that 100% of the 14 patients submitted to frozen Achilles tendon allograft could perform a single-heel rise. One delayed consolidation was noted and treated with immobilization in a weight-bearing cast.

Techniques involving various sutures for direct end-to-end repair have already been described. Yasuda et al.[28] performed Krackow sutures in 30 patients and obtained good results with substantial improvement in the mean AOFAS score (mean of 98.1). In addition, 93% of patients performed single-heel rises without difficulty. There was, however, a case of delayed wound healing.

The outcome of the treatment of Achilles tendon ruptures is mainly related to (a) strength of the triceps surae, (b) residual pain, (c) time to return to activities, and (d) patient satisfaction.

In this context, this review found similar functional, objective, and subjective results for the techniques analyzed in the study, but not enough evidence was found to indicate one technique over another.

Our review highlights that the therapeutic decision must be individualized, considering factors such as the extent of the rupture, clinical characteristics of the patient, and available resources. Despite the differences between the methods, all techniques analyzed showed a significant improvement in functional outcomes, including the strength of the triceps surae, return to work and sports activities, and higher satisfaction compared to conservative treatment. This scenario reinforces the importance of personalizing the treatment to achieve the best possible results in each case.

Conclusion

The techniques described in the literature presented similar results regarding functional, objective, and subjective aspects; no superiority of one technique in relation to another that justifies its absolute indication was found. However, surgical treatment has superior results to conservative treatment, especially in patients with high functional demand. The most appropriate surgical technique should be based on gap size, patient characteristics, and surgeon experience.

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Original Article

Radiographic study of tibiotalar alignment in normal ankles

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Abstract

Objective: Establish reference values for radiographic ankle measurements in healthy individuals. With these data, it will be possible to identify deviations from normality and assist in diagnosing and treating ankle osteoarthritis.

Methods: One hundred and fifty-six standard digital radiographs in physiological position with ankle weight-bearing in the anteroposterior (AP) and lateral incidences of 111 patients were evaluated. The parameters included in the AP incidence are the distal tibial articular surface angle, the talar tilt, and the talus center migration. The parameters in the lateral incidence are the sagittal distal tibial angle and the lateral position of the talus. Radiographic measurements were performed through inter- and intraobserver agreement, which was considered to have a significance level of 5%.

Results: There was good agreement between the measurements performed by different observers, establishing the reference values for each parameter.

Conclusion: All radiographic parameters tested showed excellent or good correlations to evaluate ankle alignment and should be considered together for a complete and adequate evaluation.

Level of Evidence IV; Therapeutic Studies; Case Series.

Keywords: Osteoarthritis; Ankle; Radiography.

Introduction

Ankle osteoarthritis can result from traumatic and clinical conditions that affect this joint. Unlike what occurs in the other weight-bearing joints of the lower limbs[1], in general, the occurrence of ankle osteoarthritis is secondary to fractures and ligament injuries[2], representing around 70% of cases[2]. Proper treatment of these injuries in the acute phase decreases the possibility of progression to complete joint degeneration. Among the causes of ankle arthrosis not associated with trauma, the most prevalent are rheumatoid arthritis (11.9%), neuropathic causes (4.9%), and primary arthrosis (7.2%)[2]. The degeneration of the tibiotarsal joint determines greater functional impairment compared to the degeneration of other joints, such as the hip or knee[1].

Two-thirds of patients with ankle osteoarthritis have an asymmetrical wear pattern. Because the ankle is part of a kinematic chain, intra-articular load distribution is not only influenced by the alignment of the tibiotalar joint itself but is highly dependent on extrinsic forces that are present due to the alignment of the distal end of the tibia and the subtalar joint, the medial spine of the foot, and soft tissue balance[1,3].

The altered morphology of the distal end of the tibia and its deviations in the sagittal and coronal planes are pointed out as important factors for mechanical overload of the ankle joint, which accelerates joint degeneration[1]. In addition, these changes also influence the prognosis after surgical procedures for treating symptomatic arthrosis, such as ankle arthroplasty and arthrodesis[4].

Study performed at the Hospital Israelita Albert Einstein, São Paulo, SP, Brazil.

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In the literature, several radiographic parameters can be found that define the normal relationship between the tibia and the talus[4-6], but their use in our environment is still not widespread. In addition, there is no significant population data on these parameters for the Brazilian population, which can make it difficult to accurately diagnose variations in normal alignment and, consequently, affect the treatment of ankle injuries.

The difficulties of standardization when positioning the patient to obtain adequate radiographic images are well known, which is essential for the reliable definition of radiographic parameters[6,7].

The objective of this study is to establish reference values for radiographic ankle measurements in healthy individuals. With these data, it will be possible to identify deviations from normality and assist in diagnosing and treating ankle osteoarthritis. It is understood that the knowledge of normal values helps diagnose patients with ankle pathologies and acts in the postoperative control, serving as a reference parameter.

Methods

This consecutive prospective study evaluated 156 standard digital radiographs in physiological position with ankle weight-bearing. The images, captured in anteroposterior (AP) and lateral incidences, were analyzed using the Carestream Vue Motion Image Viewer© system (Carestream Health) between August 2018 and July 2019, involving 111 patients. The study was approved by the Institutional Review Board and followed the ethical standards of our institution. All participants signed the informed consent form.

The radiographs were obtained following the rules established in the protocol of Tochigi et al.[8], according to which 15 cm of the distal tibial are included in the AP and lateral incidence while the patient is kept in monopodial support and the radiographic beam penetrates through the central point of the ankle joint in both positions.

The study included radiographs of both sexes, skeletally mature patients with no previous history of injuries capable of altering joint morphology.

Non-inclusion criteria include radiographs of patients with signs of congenital deformities, joint structural changes compatible with osteoarthritis, osteopenia or osteoporosis, patients with ankle fractures, operated or not, as well as patients with sequelae of fractures and major misalignments, in addition to other radiographic changes that potentially alter the local bone anatomy.

Radiographs performed outside the technical standard described above were not included.

Radiographic measurements

On the AP incidence, the distal tibial articular surface angle (Figure 1), the talar tilt (Figure 2), and the talus center migration (Figure 3) were measured.

Figure 1. The distal tibial articular surface angle, determined by the measurement between the long tibial axis and the line tangent to the distal tibial articular surface.

Figure 2. The talar tilt, determined by the measurement between the line that touches the distal tibial articular surface and another that touches the surface of the talar dome in the AP incidence.

The distal tibial articular surface angle on AP incidence was determined by the measurement between the long tibial axis and the line tangent to the distal tibial articular surface[7]. The medial distal tibial angle to the long tibial axis was considered[7,9].

The long tibial axis on AP incidence was determined from the center of the circle tangent to the medial and lateral cortices 10 cm proximal to the ankle joint and the center of another circle tangent to the three cortices of the distal tibial metaphysis, as shown by Ahn et al.[9]. The line connecting both centers is the long tibial axis on AP incidence.

The talar tilt angle was determined by the measurement between the line that touches the distal tibial articular surface and another that touches the surface of the talar dome on the AP incidence[7].

The talus center migration was determined as the shortest distance between the talus center and the long tibial axis[9,10]. Medial displacements were considered positive, and lateral displacements were considered negative[9].

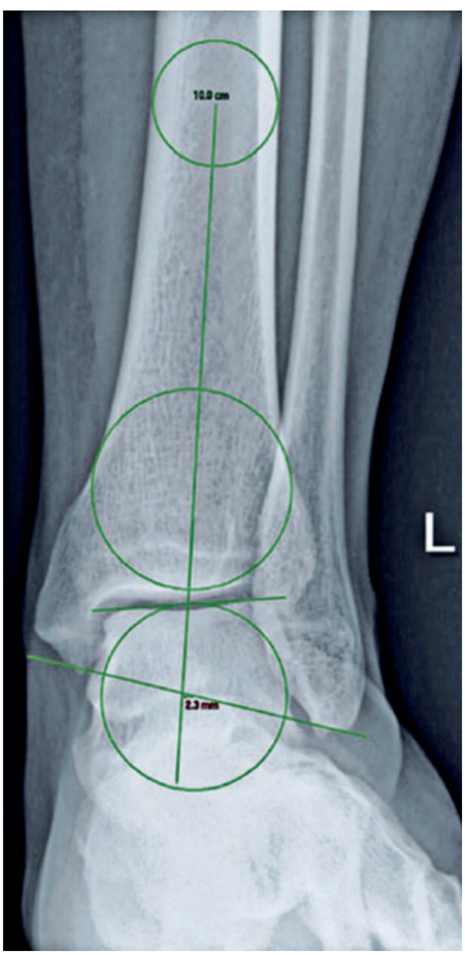

Figure 3. The talus center migration, the shortest distance from the talus center to the long tibial axis.

The center of the talus in the AP incidence corresponds to the center of a circle that touches the midpoint of the talar dome (which in the AP incidence is seen as a plateau) and, at the same time, coincides with one of the points that make up the line that touches inferiorly both tibial and fibular malleolus[9,10].

On lateral incidence radiographs, the lateral distal tibial articular surface (Figure 4), the lateral position of the talus (Figure 5), and the tibiotalar ratio (Figure 6) were measured.

The lateral distal tibial articular surface angle is formed between the long tibial axis and the distal tibial articular surface (Figure 6), determined by a line tangent to the articular surface on the lateral incidence.

The long tibial axis on lateral incidence was determined from the center of a circle fitted to the anterior and posterior cuts of the tibia located 10 cm above the ankle joint, and the center of another circle also fitted to the anterior and posterior tibial cortices 5 cm above the ankle joint; the line intersecting the center of both these circles is considered as the long tibial axis (Figure 5).

The lateral position of the talus is defined as the distance measured perpendicularly between the line of the long tibial axis and the talus center rotation. The center rotation is defined as the center of a circle fitted to the talar dome (Figure 5). Displacements to the anterior side of the long tibial axis were considered positive, and displacements to the posterior side were considered negative (Figure 5).

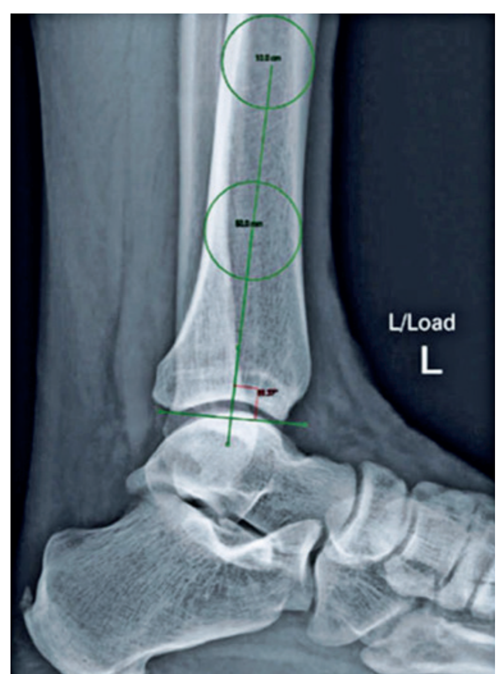

Figure 4. The lateral distal tibial articular surface, formed between the long tibial axis and the line of the distal tibial articular surface.

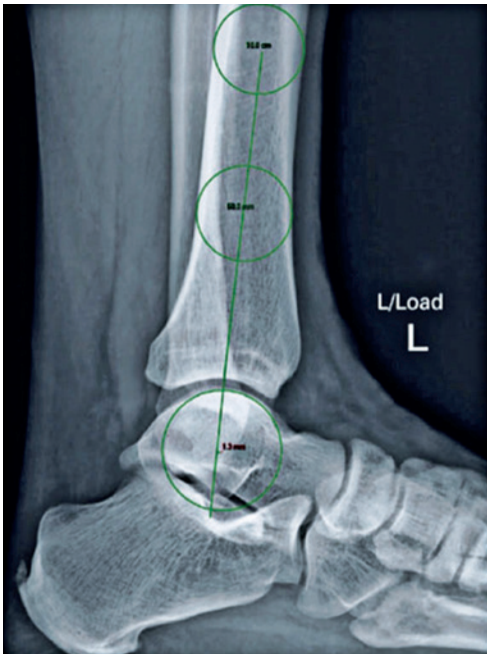

Figure 5. The lateral talus position, defined as the distance measured perpendicularly between the line of the long tibial axis and the talus center rotation.

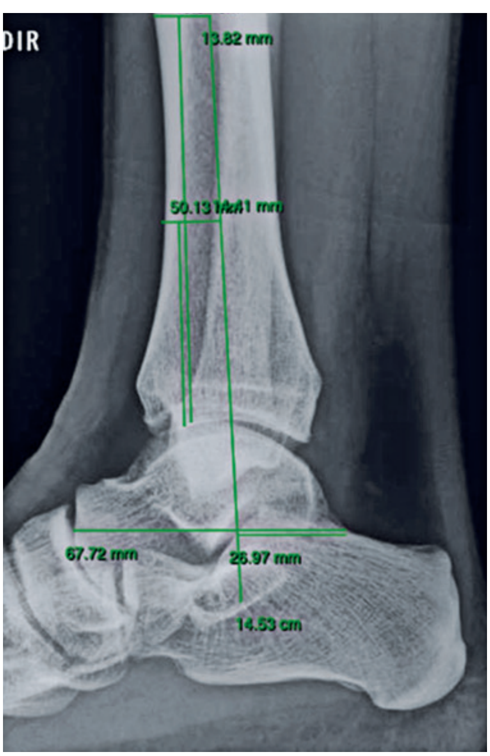

Figure 6. The tibiotalar ratio, the ratio of the intersection of the distal tibial axis line with the long talus axis.

The tibiotalar ratio uses as a reference the intersection of the distal tibial axis line with the long talus axis (Figure 6). The ratio is calculated between the total length of the talus and the distance at which the long tibial axis intersects with the talus axis (Figure 6).

Two orthopedists with different degrees and professional experience participated in these measurements: one trainee in medicine and surgery of the ankle and foot (R4) and one specialist in the ankle and foot with 25 years of experience. The evaluators performed the measurements independently and at two different times with an interval of one month.

Data analysis

The intraclass correlation coefficient (ICC) was used to measure the agreement between the measurements obtained by the two observers, separately by moments, and between the measurements obtained in the two moments, separately by the observer. As this is a method used for independent observations, patients with bilateral radiographs had one of them randomly drawn. The coefficients were followed by their respective 95% confidence intervals, and the data were represented in scatter plots and Bland-Altman plots. The measurement means were estimated by adjusting mixed linear models contemplating the dependence between the measurements obtained in the same patient.

Results

One hundred and seventy radiographs of normal ankles were selected and included in the database. Excluding images not suitable for the study as described in the non-inclusion criteria and, after the analysis, excluding possible typing and measurement errors, the final study sample included 156 radiographs from 111 different patients. Results are shown in Table 1.

The ICC values obtained were calculated to compare the measurements obtained by the two observers separately per moment and between the measurements obtained in the two moments separately per observer. It was observed that the concordances between the moments per observer are greater than between the observers per moment (Table 2).

Table 1. Estimated mean values and 95% confidence intervals for measurements obtained on ankle radiographs (111 patients)

Radiographic measurements	Estimated mean value (95%CI)
Anteroposterior incidence	
TAS (°)	90.98 (90.57; 91.38)
TT(°)	0.82 (0.73; 0.91)
TCM (mm)	-0.47 (-0.66; -0.28)
Lateral incidence	
TAS (°)	85.63 (85.16; 86.10)
Lateral talus position (mm)	1.10 (0.84; 1.35)
TTR	36.07 (35.56; 36.58)

95%CI: 95% confidence intervals; AP: anteroposterior; TAS: distal tibial articular surface angle; TT: talar tilt; TCM: talus center migration; TTR: tibiotalar ratio.

The values less than 0.2 represent low agreement, between 0.21 and 0.40 weak, between 0.41 and 0.60 moderate, between 0.61 and 0.80 good, and from 0.81 to 1.00 very good agreement.

Considering the distal tibial articular angle, no significant difference was observed by the same observer at two different times. The value of this angle was 90.98°.

Considering the talar tilt, there was a difference in the measurements of the same observer at different times (intraobserver), but there were little significant variations, approximately 1°.

In the comparative analysis between observers (interobserver), discrete variations were also observed, approximately 1°.

In the analysis of the talus migration center of each observer individually (intraobserver), a small variation in the measurements of observer B compared to observer A was noticed.

Considering the two observers (interobserver), a difference between them was noticed.

Regarding the lateral position of the talus and the lateral distal tibial articular surface, similar characteristics of the other evaluations were observed, in which the results of observer A vary more compared to observer B, but without very discrepant values. In the evaluation between the observers, a difference between the measurements obtained between the observers was noticed.

Finally, the evaluation of the tibiotalar axis showed excellent agreement between the measurements of observer A, good agreement between the observers in the first measurement, and low agreement between the measurement of observer B and between the observers in the second measurement.

Discussion

The ankle joint alignment determines its normal physiology. The disturbance of this alignment generates an anomalous distribution of loads across the joint surfaces and accelerates their wear, which culminates in degenerative joint disease. This occurs mainly after fractures and ligament injuries that can cause changes in alignment and instability. Degenerative changes associated with previous trauma, even if properly treated, can progress to degenerative disease due to trauma-related chondral injury, and arthrosis can cause secondary changes in alignment, as in other joints.

Positioning the lower limb at the time of obtaining the radiographs is essential for properly identifying the parameters. Poorly positioned limbs lead to difficulty in determining the center migration (AP incidence) and the talus center rotation (lateral incidence)[6,11], making it impossible to study joint alignment properly. The standardization of radiographic images allows the reproduction of the parameters used safely. They are also indispensable in determining the reduction quality after treating ankle fractures and in procedures for realignment (joint revision procedures) or joint ankle replacement[4,10].

The radiographic parameters on the AP incidence are the long distal tibial axis, distal tibial articular line, talar dome articular line, and talus center migration. On the lateral incidence, the parameters are the long distal tibial axis, the tibial articular surface, the talus center rotation, and the long talus axis. The definition of the long tibial axis in the lateral incidence is divergent in the literature. Tochigi et al.[6] define the long tibial axis as a line that crosses the middle of the distance between the anterior and posterior tibial cortices at 5 and 10 cm proximal to the articular surface. Barg et al.[12] define it as the line from the center of a circle in the proximal tibia, the undefined distance, to the center of a tangent circle on the anterior, posterior cortices, and articular surface. The definition of the long tibial axis in the lateral incidence used in our present study was suggested by Tochigi et al.[6] because it is easily reproducible, has less influence on anatomical deformities of the distal tibial metaphysis, and has relevance in the literature.

In the AP incidence, Ahn et al.[9] use the same tangent circle in the distal tibial cortices, as Barg et al.[12] suggested, but with a proximal point defined at 10 cm proximal. The criterion for determining the long tibial axis used in our study was that suggested by Ahn et al.[9]. We consider this easily reproducible and reliable since it has as reference a proximal

Table 2. Intraclass correlation coefficients (ICC) and 95% confidence intervals for the agreement between measurements obtained on ankle radiographs at two time points by two observers (111 patients)

Radiographic measurements	Measure 1 x Measure 2		Observer A x Observer B	
	Observer A	Observer B	Measure 1	Measure 2
Anteroposterior incidence				
TAS (°)	0.93 (0.90; 0.95)	0.98 (0.97; 0.99)	0.65 (0.48; 0.76)	0.61 (0.43; 0.73)
TT (°)	0.75 (0.63; 0.83)	0.89 (0.82; 0.93)	0.72 (0.78; 0.53)	0.66 (0.57; 0.68)
TCM (mm)	0.63 (0.46; 0.74)	0.92 (0.88; 0.94)	0.60 (-0.06; 0.81)	0.62 (0.51; 0.69)
Lateral incidence				
TAS (°)	0.93 (0.90; 0.95)	0.98 (0.97; 0.99)	0.75 (0.44; 0.86)	0.75 (0.49; 0.86)
TTR	0.84 (0.70; 0.90)	0.99 (0.98; 0.99)	0.52 (0.22; 0.70)	0.45 (0.20; 0.62)

TAS: distal tibial articular surface angle; TT: talar tilt; TCM: talus center migration; TTR: tibiotalar ratio.

point defined at 10 cm from the articular surface, different from what Barg et al.[12] suggest in which they defined the distance from which the reference should be considered.

Specifically for the distal tibial joint angle, we noticed some variability, but similar between observers, maintaining very good and good intra- and interobserver coincidence, respectively. The observed differences were very small. This radiographic parameter allows a specific assessment of the distal tibial articular surface alignment in relation to the distal tibial metaphysis.

The talar tilt and the medial distal tibial angle in normal ankles are taken in the literature as 0º (± 1º) (in the evaluation of 24 patients)[13] and 89º (87º-91º)[14]. Among the patients evaluated in our study, the mean value for the talar tilt was 0.82º, and the medial distal tibial angle was 90.98º, thus coinciding with the literature. The talar tilt on the AP incidence allows us to evaluate the congruence of the distal tibial with the talar dome, which must be properly positioned within the mortise. For this measurement, the interobserver correlation was good and excellent, and the intraobserver correlation was good, showing that it is a good way to evaluate the tibial talar alignment in the ankle joint.

The long tibial axis alignment with the talus center (evaluation of the talus center migration) measured on ankle radiography in the AP incidence was developed to measure the degree of talus migration inside the mortise[9,10]. The lateral position of the talus allows for the classification of the talus as medial, neutral, or lateral[5].

The interobserver agreement was moderate and good, and we attributed this variation to differences in experience with radiographic images among the participants. However, the variability between the two observers was small, remaining within values considered normal in the literature[4,10]. Interestingly, the intraobserver variation was substantially lower in the second assessment (good in the first and excellent in the second measurement). This may indicate the need for training to perform complex measurements. The values for talus center migration described by Yi et al.[4] are 0.4 mm, ranging from 2.1 mm to -1.4 mm, considering 73 radiographs of skeletally mature individuals without deformities or lower limb axis deviations. In the initial study by Ahn et al.[10], the value was 3.5mm, ranging from 1.9 to 5.2 mm. However, as this study focused on alignment after supramalleolar osteotomy in 18 ankles with focal medial osteoarthritis, secondary deviations due to joint wear must be considered. In the present study, the normal value was -0.47 mm.

In the evaluation of the distal tibial articular surface angle, it is noted that there was less variation in the measurements of observer B compared to A. However, the differences remain within acceptable limits (between ± 3º). According to the literature, the lateral distal tibial angle is considered normal 80º[15]. The population studied in our study was 85.63º.

In the lateral incidence evaluation, in the talus lateral position, Tochigi et al. [6] observed a normal value of 33.4 ± 3.3%, which does not contrast with our results, in which the value found was 36.07 (ranging from 35.56 to 36.58). Obtaining such a reference allows positional evaluation in the axial incidence of the tibiotalar joint, with less interference from the position of the joint in flexion or extension. In the literature, the normal range of the talus lateral position for normal ankles ranges from -0.8076 mm to 3.1496 mm, with a mean of 1.17 mm in the series by Veljkovic et al.[5] with 82 ankles. Magerkurth et al.[16], in a series of 52 patients without ankle pathologies, have the talus center position 1.6 mm anterior to the anatomical tibial axis as normality. Our results are in accordance with these values, with a mean of 1.10 mm.

In the tibiotalar ratio, the intraobserver coefficients were excellent, but the interobserver coefficients were weak in both measurements. This alignment parameter suffers interference from the presence of stretching or degenerative changes in the posterior portion of the talus, making it difficult to standardize the parameters for determining the long talus axis due to the final measurement. This parameter showed the poorest interobserver agreement among the radiographic measurements, reflecting the challenges associated with its evaluation.

There are several options for the surgical treatment of patients with ankle arthrosis: osteophyte resection and synovectomy, arthrodiastasis, supramalleolar osteotomies for ankle realignment, fresh cadaver osteochondral allograft, ankle arthrodesis, and total ankle arthroplasty[17]. Regardless of the chosen method, reestablishing ankle alignment is essential, as failure to do so compromises the outcome of the procedure[4]. This shows the importance of defining normal parameters.

The main limitations faced in our study are related to the parameters adopted, the sample, and the body segment studied.

Other parameters for measuring radiographic alignment, also described in the literature, can contribute to the study of the ankle joint, such as using the mechanical axis of the lower limbs, unlike the parameters used in the current study. Another technical limitation concerns the radiographic parameters used to define the lateral talus position. Due to its irregular shape, alignment with the radiographic cassette can be unsatisfactory (ideally, the ankle should be positioned with both malleoli overlapping). Consequently, determining the talus center rotation using a circle tangent to the articular surface may be compromised, leading to measurement variability.

Another limitation is related to the sample. This study was performed in a single center with a specific population, so extending the data to the Brazilian population may not portray reality.

The various parameters created and tested in other countries need to be validated for our population since there may be substantial variations in the normality values given the ethnic differences of each nationality.

Benevides et al.[18] propose that a minimal radiographic evaluation of the tibiotalar alignment should include the following parameters in the AP incidence: the distal tibial joint angle, the talar tilt, and the talus center migration. The lateral incidence should include lateral distal tibial angle and lateral talar station. Our study complements this proposal, bringing together all the tested parameters that are interesting for evaluating ankle alignment and should be considered to allow a complete and adequate evaluation. In the lateral incidence, the talus position under the distal tibial, the lateral talus position proved to be easier to assess and less influenced by degenerative changes in the subtalar joint than the tibiotalar ratio.

Conclusions

The reference values for normal weight-bearing radiographic measurements for the studied population, which show excellent or good inter- and intraobserver correlations for the AP incidence, were the distal tibial articular angle between 90.57° and 91.38°, the talar tilt between 0.73° and 0.91°, and the alignment between the long tibial axis and the talus center between -0.66 and -0.28°. For the lateral incidence were the distal tibial articular angle between 85.16° and 86.10° and the lateral talus position between 0.84 mm and 1.35 mm.

It is understood that knowledge of these normal values, which show good correlation, helps diagnose patients with ankle pathologies and plays a role in postoperative control, serving as a reference parameter.

Authors' contributions: Each author contributed individually and significantly to the development of this article: PCB *(https://orcid.org/0000-0002-4209-0564) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, data collection, bibliographic review, survey of the medical records, approved the final version, wrote the article; CMM *(https://orcid.org/0009-0001-5071-9764) Interpreted the results of the study, participated in the review process, bibliographic review, approved the final version; PJF *(https://orcid.org/0000-0003-1296-6665) Interpreted the results of the study, participated in the review process, bibliographic review, formatting of the article, approved the final version; CASN *(https://orcid.org/0000-0002-9286-1750), and JFMA *(https://orcid.org/0000-0002-7664-2064), and ALGS *(https://orcid.org/0000-0002-6672-1869), and ASOJ *(https://orcid.org/0000-0002-7348-4697), and GBBS *(https://orcid.org/0000-0001-9004-3909), and RAM *(https://orcid.org/0000-0002-7830-8318) Interpreted the results of the study, participated in the review process, approved the final version; MPP *(https://orcid.org/0000-0003-0325-8050) Interpreted the results of the study, participated in the review process, data collection, wrote the article, participated in the review process, approved the final version.. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Original Article

Arthroscopic assessment in acute ankle fractures

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Abstract

Objective: The goal of the present study is to carry out an inventory of intra-articular injuries through arthroscopy in patients with ankle fractures.

Methods: This observational cross-sectional study evaluated 28 patients who underwent ankle arthroscopy before and after ankle osteosynthesis. Five items were assessed: medial malleolus reduction, intra-articular loose bodies, osteochondral lesion, lateral ligament integrity, and deltoid integrity.

Results: Sample included 12 (42.86%) male patients and 16 (57.14%) female patients aged around 45.7 years. Out of 28 cases, 20 were Danis-Weber type B fractures. Intra-articular lesions of the ankle were found in 24 patients. A total of 17 (60.71%) patients had syndesmotic injuries, while 16 (57.14%) patients had osteochondral lesions. Lateral and medial ligament injuries were found in five patients each. Medial malleolar fractures were identified in 12 patients, four of which were poorly reduced.

Conclusion: Ankle fractures are commonly associated with intra-articular ankle injuries. Danis-Weber type C fractures frequently present with severe osteochondral and ligamentous injuries.

Level of evidence IV; Therapeutic studies; Case series.

Keywords: Arthroscopy; Ankle fractures; Ankle joint.

Introduction

Approximately 70% of patients with unstable ankle fractures treated with open reduction and internal fixation (ORIF) present good outcomes[1], but some patients have unpredicted worse functional outcomes[2].

As arthroscopy allows the identification of traumatic cartilage injuries to which unsatisfactory results can be attributed in fracture treatment[3-5], there has been an increase in arthroscopy-assisted ORIF of acute ankle fractures[6].

The goal of the present study is to carry out an assessment of intra-articular injuries in patients with ankle fractures using arthroscopy.

Methods

Patient selection and assessment

The present observational cross-sectional study involved a population of patients with ankle fractures treated surgically between August 2020 and August 2021. After Research Ethics Committee approval was obtained, patients between 18 and 60 years old with acute fractures (up to 21 days) were included in the study upon signing an informed consent form. Patients with isolated unimalleolar fracture, tibial pilon fracture, open fracture, infection, or neoplasia of the lower limbs, as well as patients with a score equal to or greater than 3 as per the American Society of Anesthesiologists (ASA) and patients with external fixation of the ankle, were excluded.

Participants were evaluated clinically and by ankle radiographs (anteroposterior, true anteroposterior, and lateral views), foot radiographs (anteroposterior, oblique, and lateral views), and a computed tomography of the ankle. Preoperative radiographs were evaluated according to Danis-Weber's classification by two independent surgeons.

Surgical procedures

Surgical protocol was similar for all cases. Patients were in the supine position with a cushion below the ipsilateral hip. Heels were positioned at the end of the operating table,

Study performed at the National Institute of Traumatology and Orthopaedics, Rio de Janeiro, RJ, Brazil

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allowing ankle dorsal and plantar flexion, as well as stress maneuvers during arthroscopy. A tourniquet was applied to the proximal thigh to prevent compression of leg muscles and interference with the ankle arthroscopy access.

The procedure began with the first stage of ankle arthroscopy. An anteromedial longitudinal incision, medial to the tibialis anterior tendon, was performed using a #11 blade scalpel. Blunt dissection was completed until reaching the joint capsule, preventing injury to the sensory nerves. The ankle joint was assessed using a trocar with a conical blunt tip and cannula, followed by the introduction of a 3.5 mm arthroscope. The ankle and dorsum of the foot were palpated before the anterolateral portal incision to avoid lesions of the intermediate dorsal cutaneous nerve. Then, skin incision was performed and blunt dissection was used to reach the deeper layers up to the joint capsule.

Arthroscopy was performed without joint traction. The joint was irrigated with 0.9% saline solution supplied by gravity flow and, after cleaning the joint, an assessment was carried out to look for injuries. The distal tibia and talar dome were inspected for osteochondral injuries; the medial and posterior malleolus, for fractures; the deltoid and lateral ligament complex, for ruptures; and the distal fibula, to view the fracture, as well as the relationship of the fibula with the distal tibia, so as to evaluate syndesmosis injury. Loose bodies, where present, were removed. Visualization of the posterior malleolus was hampered by not using posterior portals in the ankle and not using joint traction.

Articular cartilage lesions were classified according to depth and location as determined by arthroscopic inspection and palpation with a millimeter probe considering the largest diameter of the lesion and its greatest depth. The location of talar osteochondral lesions was determined according to the quadrants proposed by Raikin et al.[7] and classified according to the International Cartilage Repair Society (ICRS) grading system[8].

A syndesmosis stress test was performed during arthroscopy, followed by parallel or single screw fixation if considered unstable. Once arthroscopy was completed, fractures underwent ORIF.

The second step of arthroscopy began after ankle osteosynthesis, evaluating the quality of medial malleolus reduction. The stability achieved after syndesmosis fixation was assessed by visualizing the fixed syndesmosis as well as by carrying out a stress test (external rotation of the ankle) while checking the behavior of the syndesmosis. If unstable, a new fixation attempt was made. Then, the stability of the deltoid and lateral ligament complex after repair were evaluated.

Statistical analysis

Data were tabulated in a Microsoft Excel® spreadsheet for subsequent analysis and summarized by frequency. Chi-square test was used for comparing the frequencies of intra-articular findings, quality of reduction, and lesion location.

Results

Twenty-eight participants who underwent arthroscopically-assisted ankle osteosynthesis were included (Figure 1). Demographic data is presented in Table 1.

Intra-articular injuries were identified in 85.71% of study participants. The most commonly observed changes were syndesmosis injury, in 17 participants (60.71%); presence of osteochondral injuries, in 16 participants (57.14%); and ligament injuries (35.7%) and loose bodies (35.7%), in 10 participants each. In four individuals, no intra-articular lesions were found.

Intra-articular findings were identified in 100% of type C Danis-Weber fractures and in 80% of type B fractures (Table 2). Statistical analysis did not reveal differences among intra-articular findings regarding the type of fracture ($p = 0.95$).

Medial malleolus fractures were present in 12 participants. Statistical analysis did not reveal any difference in the quality of reduction of the medial malleolus considering the type of fracture ($p = 0.23$; Table 3).

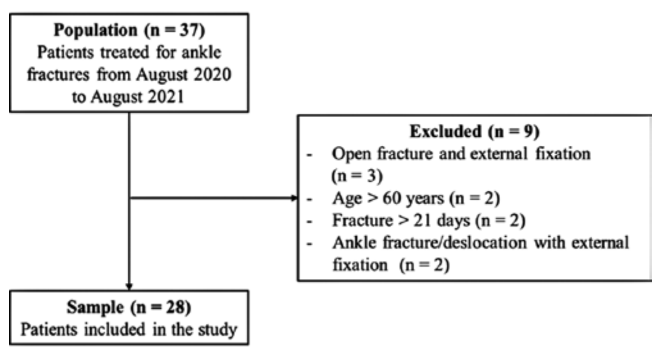

Figure 1. Study flowchart.

Table 1. Demographic data of the population included in the study.

Characteristics	
Age in years at lesion (Average ± SD)	45.7 ± 10.88
Sex	
Male	8 (33.33%)
Female	16 (66.67%)
Comorbidities	
Diabetes	5 (20.8%)
Hipertension	5 (20.8%)
Tabagism	4 (16.67%)
Danis-Weber classification	
Danis-Weber type B	20 (71.43%)
Danis-Weber type C	8 (28.57%)

Raikin's zone 6 presented 63.16% of osteochondral lesions. Statistical analysis did not reveal differences in the location of the injuries considering the type of fracture (p = 0.6; Table 4).

Lesions located in Raikin's zone 6 were deeper than those observed in zone 4 and zone 1 both in patients with Danis-Weber type B and Danis-Weber type C fractures (Table 5).

Discussion

The present study, an arthroscopic assessment of intra-articular injuries in patients with acute Danis-Weber types B and C ankle fractures, identified intra-articular injuries that would not have been diagnosed without the aid of arthroscopy.

Poor results in ankle fracture treatment may occur due to unrecognized and, therefore, untreated intra-articular injuries[9]. In a systematic review including patients with ankle fractures who underwent treatment with ORIF, only 79% had good to excellent long-term outcomes, not necessarily correlating with fracture severity, despite anatomical reduction[10]. Data on functional outcome after Danis-Weber type B ankle fractures in patients submitted to ORIF showed that, after two years of surgery, 36% of patients had complete recovery, 44% reported problems during work, and 61% reported problems in sports activities[11]. On the other hand, a retrospective study showed that arthroscopy-associated ORIF did not increase the complication rate and led to improvements in patient-reported outcomes, although arthroscopy made the procedure last 10 minutes longer than usual[12].

In the present study, intra-articular injuries were identified using arthroscopy in 89.29% of participants with ankle fractures, of which 54.58% presented osteochondral injuries. Arthroscopy-assisted treatment of ankle fractures increased from 3.65 to 13.91 per 1,000 ankle fractures, respectively, in 2010 and 2019[13]. Osteochondral injuries of the ankle frequently cause pain and disability[14,15]. Chondral injuries were detected in 78% of patients with acute ankle fractures undergoing arthroscopy, but in 100% of those who had associated dislocation[16]. Prevalence of intra-articular injuries identified with arthroscopy in patients with ankle fractures ranged from 77.5%[17], through 63.3%[18], to 62.2%[19] depending on the study.

Table 2. Intra-articular pathological findings in each patient according to the Danis-Weber classification

Intra-articular findings	Danis-Weber type B fracture	Danis-Weber type C fracture	Total
Loose body	6	4	10
Osteochondral lesion	10	6	16
Syndesmotic lesion	9	8	17
Ligamentary lesion	6	4	10
No lesion	4	0	4

Table 3. Quality of medial malleolus reduction

Quality of reduction	Danis-Weber type B fracture	Danis-Weber type C fracture	Total
Anatomic	7	1	8
Non-anatomic	2	2	4

Table 4. Location of the talar osteochondral injury in relation to the type of fracture

Location of the osteochondral injury	Danis-Weber type B frature	Danis-Weber type C frature	All fractures
Zone 1	0	1	1 (5.26%)
Zone 2	2	1	3 (15.79%)
Zone 3	0	0	0
Zone 4	3	0	3 (15.79%)
Zone 5	0	0	0
Zone 6	7	5	12 (63.16%)
Zone 7	0	0	0
Zone 8	0	0	0
Zone 9	0	0	0

Table 5. Size, location, depth, and International Cartilage Repair Society classification of osteochondral lesions

Lesion	Size	Depth	Location	ICRS classification
A	< 2 mm	< 2 mm	6	2
B	< 2 mm	2-4 mm	6	3
C	2-4 mm	< 2 mm	6	2
D	2-4 mm	2-4 mm	6	3
E	< 2 mm	< 2 mm	4	2
F	2-4 mm	< 2 mm	4	2
G	< 2 mm	< 2 mm	1	2
H	2-4 mm	< 2 mm	2	2
I	< 2 mm	< 2 mm	2	2
J	2-4 mm	< 2 mm	2	2
L	< 2 mm	< 2 mm	4	2
M	2-4 mm	2-4 mm	6	3
N	< 2 mm	< 2 mm	6	2
O	< 2 mm	2-4 mm	6	3
P	2-4 mm	< 2 mm	6	2
Q	< 2 mm	< 2 mm	6	2
R	< 2 mm	2-4 mm	6	3
S	2-4 mm	< 2 mm	6	2
T	2-4 mm	< 2 mm	6	2

ICRS: International Cartilage Repair Society.

In the present study, we diagnosed 16 osteochondral lesions that would not have been identified and treated if arthroscopy had not been performed. The majority of osteochondral lesions were found in the talus (87.5%), which is in line with previously published studies(5,20). Most talar injuries were medial, in the Raikin zone 6 (67.16%)(6). Since arthroscopy was performed without traction, no lesions were identified on the posterior talus. A retrospective study demonstrated that 75% of involved patients had new injuries diagnosed us arthroscopy, with osteochondral injuries (41.9%) and posterior malleolus fractures (32.6%) being the most common ones(21). In the present study, Danis-Weber type C fractures showed higher incidence of osteochondral injuries compared to type B fractures, as reported by another author(5). On the other hand, other studies found no significant differences in the incidence of osteochondral injuries between Danis-Weber type B and type C ankle fractures(2,4).

The syndesmosis, which is fundamental in maintaining ankle stability(22), can be injured either isolated or in association with ankle fractures(23). In Danis-Weber type C fractures, syndesmosis injuries are present in up to 80% of cases(24,25). In this study, we identified syndesmosis injuries, respectively, in 100% and 45% of participants with Danis-Weber type C and type B fractures. The integrity of the syndesmosis is not well demonstrated in external rotation Danis-Weber type B fractures, but some studies report injuries in up to 40% of cases(24,25). Diagnosing syndesmosis injury can be difficult due to its anatomical variation(26,27). The squeeze test and the ankle external rotation test(26), when positive, are highly specific, although presenting low sensitivity for identifying syndesmotic injury(28).

Ankle arthroscopy is both a diagnostic and therapeutic method(29), providing a direct view of the syndesmosis during dynamic testing(30). Direct visualization of articular lesions allows a higher safety and precision in diagnosis and treatment, besides guiding extra-articular stabilization, if indicated(29). The syndesmosis is considered unstable when a diastasis over 2 mm is identified(31,32). In the present study, all syndesmosis injuries were diagnosed and treated with the aid of arthroscopy. Some studies evidenced that postoperative syndesmosis malreduction is detected in 16% of plain radiographs and in up to 52% of computed tomography scans(33-35). It is believed that these unsatisfactory results are largely attributable to indirect reduction without tibiofibular joint visualization, as well as to the difficult reduction assessment, dependent on inaccurate fluoroscopic images(27,36). Reduction accuracy can be improved by direct visualization of the syndesmosis(27,37).

The medial ligament complex has an important role in ankle joint stability(38), and many case series have reported satisfactory results and no complications with the surgical treatment of deltoid ligament associated to ankle fracture(39,40). Exploring the deltoid ligament is recommended where there is a doubt on the medial clear space congruence in true anteroposterior radiograph(41). On the other hand, a systematic review suggested that, after adequate fibular reduction and medial clear space normalization, exploring and reconstructing the deltoid ligament would not be necessary(18). Hence, it is still unknown whether an untreated deltoid ligament lesion would be a source of persistent pain or pronation deformity. A statistically significant correlation between the lack of deltoid ligament repair and Danis-Weber type C ankle fracture malreduction and failure was identified(42). In the present study, we found five deltoid ligament partial injuries without ankle instability, and hence no repair was performed. Arthroscopy helps visualizing the deltoid ligament during stress maneuvers, which, combined with fluoroscopic evaluation, gives the surgeon more confidence to decide whether or not to reconstruct this structure.

In fractures of the medial malleolus, an articular surface step-off is probably more related to the risk of post-traumatic osteoarthritis than a medial cortical surface step-off(43). In the present study, reduction was observed in 12 medial malleolus fractures, all of these being evaluated by arthroscopy. In four participants, reduction was not anatomical. Of the participants in whom arthroscopy did not reveal anatomical reduction, in two (50%) intraoperative radioscopy did not show any deviation that was noticeable using the method. Therefore, arthroscopy was essential in the diagnosis of joint mal reduction, since cortical alignment alone was not reliable. In these patients, osteosynthesis was redone, achieving anatomical reduction in one of the two participants.

The present study's strength is that it evaluated patients at a same treatment center and with similar fracture patterns. However, we can mention as limitations the lack of a control group and the lack of posterior ankle joint evaluation during arthroscopy.

Conclusion

Ankle intra-articular injuries are diagnosed and treated with arthroscopy-assisted osteosynthesis. Danis-Weber type C fractures present a higher incidence and severity of osteochondral and ligament injuries than type B fractures.

Authors' contributions: Each author contributed individually and significantly to the development of this article: ZRSMP *(https://orcid.org/0000-0003-4758-0893) 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, formatting of the article, clinical examination; TASN *(https://orcid.org/0000-0001-7988-6307) 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; VAM *(https://orcid.org/0000-0003-0241-5237) 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, survey of the medical records, formatting of the article, clinical examination; EBS *(https://orcid.org/0000-0001-8577-6403) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, statistical analysis, bibliographic review, formatting of the article, clinical examination. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Original Article

Simultaneous dual approach in Hawkins type II fractures: Maximum benefit at low risk?

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Abstract

Objective: The aim of this study was to evaluate the outcomes of Hawkins type II fractures treated with a simultaneous dual approach.

Methods: A retrospective multicenter study was conducted at four major trauma centers. Patients with Hawkins type II closed talar neck fractures managed by a simultaneous dual approach with complete preoperative medical records and a minimum follow-up of six months were included.

Results: Eighteen patients were identified. The anatomical reduction was achieved in 17 cases, with a mean follow-up of 53.57 ± 31.77 months (range 8 to 116 months), and the American Orthopaedic Foot & Ankle Society (AOFAS) score was 91.42 ± 7.66 points (range 75 to 100). There were two cases of subtalar arthritis (11%) and two cases of partial avascular necrosis of the talar body (11%), all of them asymptomatic and not requiring secondary surgical procedures up to the latest clinical follow-up.

Conclusion: The simultaneous dual approach is a safe and reliable strategy for managing Hawkins type II talar neck fractures without significantly compromising the talar circulation. We recommend that future prospective studies with a larger sample be conducted to validate these findings further.

Level of evidence IV; Therapeutic studies; Case series.

Keywords: Foot bones; Fracture healing; Bone avascular necrosis.

Introduction

Talar neck fractures with subtalar joint subluxation or dislocation, classically known as Hawkins type II, are the most frequent variety reported in the literature of these uncommon foot injuries[1,2].

Over the past 20 years, substantial improvements have occurred concerning their definitive surgical management. Combined lateral and medial access seems to be the most recommended since it is possible to visualize both sides of the segment and thus better control reduction, avoiding residual displacement[3-7]. The major concern is the potential threat to talus body vascularity: the additional damage involved in two close surgical approaches could increase the chance of developing osteonecrosis. Due to the low incidence of these injuries, the published evidence with this strategy remains scarce and limited to some case series, preventing the ability to draw definitive conclusions[1,5-9].

The aim of this study is to evaluate the outcomes of Hawkins type II fractures treated with a simultaneous dual approach in terms of reduction quality, functional results, and complication rates focusing on avascular necrosis and peritalar arthritis.

Considering all these aspects, the hypothesis is that this simultaneous dual approach is safe and highly recommended.

Study performed at the Sanatorio Allende, Córdoba, Córdoba, Argentina.

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Methods

A retrospective multicenter study was conducted at four level 1 trauma centers. Patient and clinical data were collected using a shared form completed after obtaining informed consent from all cases. The protocol was approved by the Hospital's Ethics and Research Commission.

Patients with Hawkins type II closed talar neck fractures treated by simultaneous dual approach with complete medical records, including preoperative radiographs and computed tomography (CT) scan, and a minimum follow-up of six months were included. Patients with open injuries, previous history of osteochondral lesions to the talus, simultaneous fixation of the calcaneus, and rheumatoid pathologies were excluded.

The surgical technique used an anterolateral approach starting from the lateral aspect of the ankle joint in line with the extensor digitorum longus muscle towards the base of the fourth metatarsal and anteromedial access between the anterior and posterior tibial tendons beginning over the medial malleolus and progressing towards the tuberosity of the navicular bone (Figure 1).

Medical data recorded was entered into an Excel spreadsheet including patient demographics, comorbidities, soft tissue condition, initial damage control surgery, time to definitive fixation, quality of reduction assessed by CT scan (anatomic or not; based on a 2 mm articular step), functional results based on the American Orthopaedic Foot & Ankle Society (AOFAS) hindfoot score and patient's reported satisfaction (very satisfied, satisfied, dissatisfied, very dissatisfied), early complications (superficial or deep infection, wound dehiscence or deep vein thrombosis), late complications (nonunion, avascular necrosis, subtalar and/or ankle arthritis), and need for secondary procedure.

Results

Between January 2014 and June 2023, 18 patients were identified with closed Hawkin type II talar neck fractures treated by open reduction and internal fixation by a simultaneous dual approach technique (Table 1). The mean age of the cohort was 30.8 years (range 15 to 45 years). Six cases (40%) required initial damage control surgery involving closed reduction and percutaneous pinning fixation.

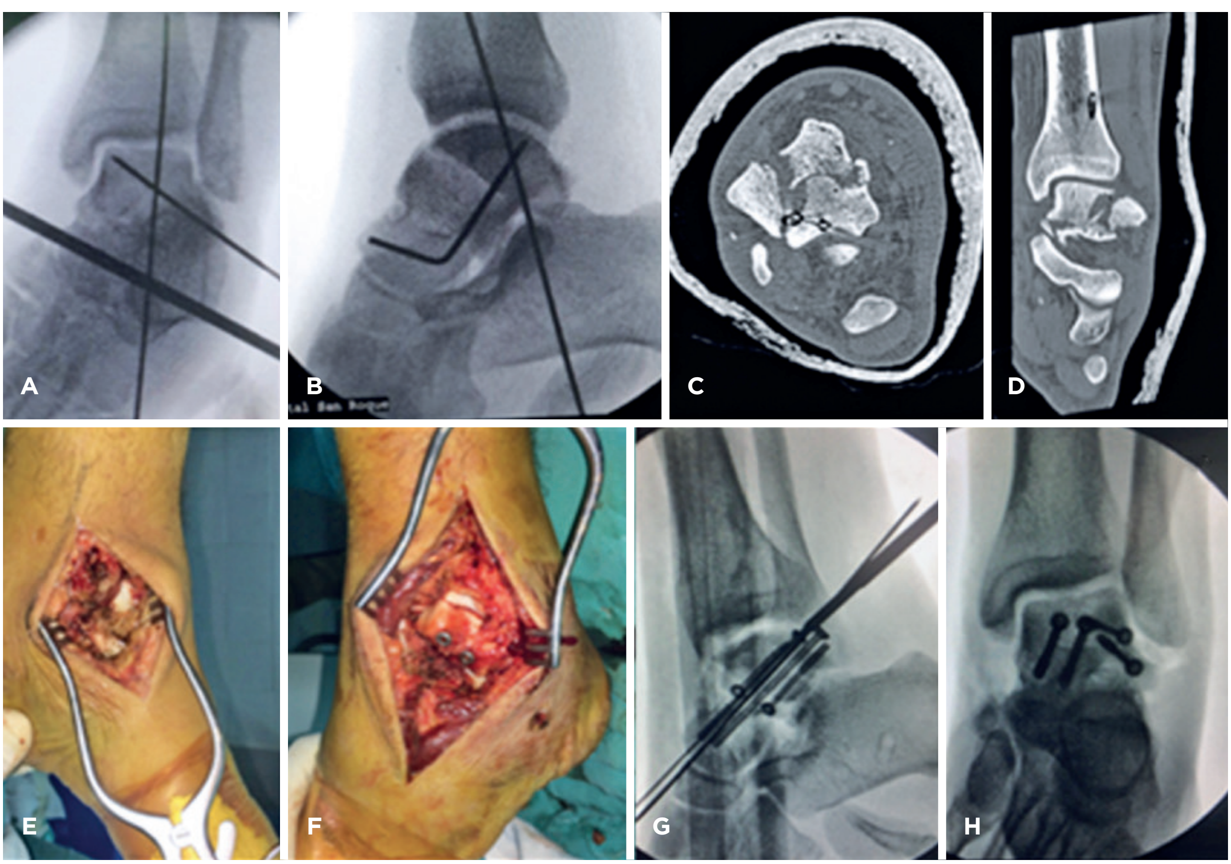

Figure 1. Sample Case. Description: (A and B) Anteroposterior and lateral radiographs of the talus after initial closed reduction. (C and D) Post-reduction axial computed tomography. (E) Anteromedial approach. (F) Anterolateral approach. (G and H) Anteroposterior and lateral radiographs of open reduction and internal fixation.

The mean time to definitive surgery was 19.42 ± 32.13 days (range 1 to 144 days). Three cases required surgical manipulation on the medial malleolus through the anteromedial approach, either as a Chevron osteotomy (1 case) or surgical fixation of an associated medial malleolus fracture (2 cases).

Anatomical reduction was achieved in 17 of 18 cases. With a mean follow-up of 53.57 ± 31.77 months (range 8 to 116 months), the AOFAS score was 91.42 ± 7.66 points (range 75 to 100). Patient satisfaction in the postoperative was 11 very satisfied, seven satisfied, and none dissatisfied.

Five patients (27%) reported complications (Figure 2). There was one early complication: a deep infection that required debridement and antibiotic therapy with a favorable resolution. Late complications included two cases of subtalar arthritis (11%) and two cases of partial avascular necrosis of the talar body (11%), all of them asymptomatic and not requiring secondary surgical procedures up to the latest clinical follow-up.

Discussion

Talar neck fractures involving subtalar joint displacement are challenging injuries that carry a significant risk of complications, leading to long-term functional impairment and disability[10,11]. Among the most common complications are subtalar arthritis, avascular necrosis, malunion, and nonunion. The literature consistently emphasizes the importance of achieving anatomic reduction and rigid internal fixation while preserving the blood supply to the talar body to minimize these complications. However, there is ongoing debate regarding the optimal surgical approach.

The dual incision technique, combining an anteromedial and anterolateral approach, has become a standard for talar neck fractures, providing excellent exposure and enabling precise reduction. Several studies have highlighted the

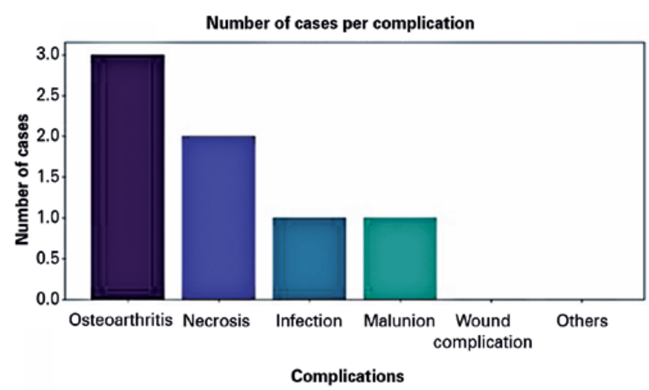

Figure 2. Distribution of complications.

Table 1. Sample description.

N	Age	Sex	PH	Damage control surgery	Osteotomy MM	Reduction CT	Follow-up (m)	AOFAS	Satisfaction	Complications					Others	2nd surgery
										Early		Late				
										Infection	Wound complication	Artrosis	AVN	Malunion		
1	21	M	No	Yes	No	A	29	84	Satisfied	No	No	Yes	No	No	No	Yes
2	42	F	No	Yes	No	NA	98	75	Satisfied	No	No	No	Yes	Yes	No	No
3	23	M	No	Yes	No	A	81	100	Very satisfied	No	No	No	No	No	No	No
4	39	F	No	No	No	A	81	90	Very satisfied	Yes	No	No	No	No	No	No
5	27	M	No	No	No	A	73	90	Very satisfied	No	No	No	No	No	No	No
6	45	M	No	Yes	No	A	64	95	Very satisfied	No	No	Yes	No	No	Yes	Yes
7	22	M	No	No	No	A	63	90	Very satisfied	No	No	No	No	No	No	No
8	24	F	No	No	Yes	A	54	80	Satisfied	No	No	Yes	No	No	No	Yes
9	27	F	No	No	Yes	A	53	90	Satisfied	No	No	No	Yes	No	No	No
10	22	M	No	No	No	A	50	100	Very satisfied	No	No	No	No	No	No	No
11	43	M	No	Yes	Yes	A	37	90	Very satisfied	No	No	No	No	No	No	No
12	15	F	No	Yes	No	A	36	100	Satisfied	No	No	No	No	No	No	No
13	42	M	No	No	Yes	A	25	90	Satisfied	No	No	No	No	No	No	No
14	28	F	No	No	Yes	A	13	100	Very satisfied	No	No	No	No	No	No	No
15	43	F	No	No	No	A	8	90	Satisfied	No	No	No	No	No	No	No
16	33	F	No	No	No	A	30	93	Very satisfied	No	No	No	No	No	No	No
17	20	M	No	No	No	A	14	100	Very satisfied	No	No	No	No	No	No	No
18	35	M	No	No	No	A	14	100	Very satisfied	No	No	No	No	No	No	No

A: Anatomical; NA: Non-anatomical; (m): Months; AOFAS: The American Orthopaedic Foot & Ankle Society; AVN: Avascular necrosis PH: Pathological history CT: Computed tomography.

advantages of this approach in terms of improved fracture alignment and reduced rates of residual displacement. In our series, anatomical reduction, confirmed by postoperative CT scan, was achieved in 17 out of 18 cases, supporting the efficacy of this technique. Our results align with those of Bastos et al.[12], who also found that a dual approach resulted in satisfactory fracture reduction and functional outcomes in their cohort of eight patients with Hawkins type II and III fractures. Furthermore, studies by Lindvall et al.[13] and Liu et al.[14] reported similar findings, showing that the dual approach significantly reduced the risk of malalignment and secondary complications. A systematic review and meta-analysis by Giordano et al.[15] found that dual approaches, particularly for fractures classified as Hawkins type II, III, and IV, were associated with favorable fracture reduction and low rates of post-traumatic arthritis and avascular necrosis. In their study, anatomical reductions were achieved in most cases, and only a small percentage of patients developed avascular necrosis, similar to our findings[15]. Giordano et al.[15], along with those of Fleuriau Chateau et al.[3] and Wu et al.[16], emphasize that the dual approach allows for better control of fracture alignment and reduces the incidence of subtalar arthritis when compared to single approaches. While the risk of avascular necrosis[17,18] remains a concern in managing talar neck fractures, our study demonstrated that its incidence was low, with only two cases of partial, asymptomatic that did not impact the patients' functionality or pain. This result is consistent with the findings of Bastos et al.[12], who reported no significant increase in avascular necrosis with the dual approach, even when a medial malleolar osteotomy was required. Additionally, studies by Liu et al.[14] and Maceroli et al.[19] reported similarly low rates of avascular necrosis in patients treated with a dual approach, even in more severe fractures. Despite its advantages, the dual approach comes with challenges. A study by Ohl et al.[20] raised concerns about the potential damage to surrounding soft tissues and the increased complexity of performing two incisions. However, our study, along with the review by Giordano et al.[15], suggests that these risks can be minimized with careful surgical technique and meticulous tissue handling. Furthermore, the improved fracture reduction achieved with the dual approach justifies its use, especially in fractures with significant displacement or those at high risk of complications. Additionally, the dual approach has been associated with improved functional outcomes, as reflected in the mean AOFAS score of 91 points in our cohort. This aligns with studies by Fleuriau Chateau et al.[3] and Lindvall et al.[13], which demonstrated similar functional results with dual approaches. These outcomes support the hypothesis that, while technically demanding, the dual approach offers significant benefits in both fracture reduction and long-term functionality.

Our study has limitations, including the small sample size and retrospective design, which introduce the potential for selection and data collection biases. These concerns are echoed by Giordano et al.[15], who also highlight the need for larger, prospective studies to validate further the benefits of dual approaches in talar neck fractures. Additionally, while our follow-up period was relatively long (mean 4 years), the relatively short follow-up in some studies may affect the long-term outcomes, particularly concerning the development of arthritis or avascular necrosis.

Conclusion

The simultaneous dual approach remains a highly effective technique for managing complex talar neck fractures. It provides superior exposure, reduces the risk of malalignment, and results in satisfactory clinical outcomes. While concerns about avascular necrosis and vascular compromise are valid, our findings and those in the literature suggest that these risks can be minimized with proper technique. Further research is needed to solidify these results and explore the long-term benefits of the dual approach in talar neck fractures.

Authors' contributions: Each author contributed individually and significantly to the development of this article: JPA *(https://orcid.org/0000-0001-9662-0367) Conceived and planned the activities that led to the study, wrote the article, data collection, bibliographic review; IJT *(https://orcid.org/0000-0001-5134-1428) Bibliographic review, performed the surgeries; LMVB *(https://orcid.org/0000-0001-8596-5466) Performed the surgeries; EC *(https://orcid.org/0000-0002-4893-6006) Participated in the review process, formatting of the article; GSM *(https://orcid.org/0009-0003-6734-3294) Performed the surgeries, survey of the medical records; MARN *(https://orcid.org/0009-0004-4470-2490) Survey of the medical records, clinical examination, participated in the review process; FS *(https://orcid.org/0009-0000-7101-9145) Statistical analysis, interpreted the results of the study; FPS *(https://orcid.org/0000-0002-2376-4834) Performed the surgeries, data collection, conceived and planned the activities that led to the study. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Original Article

Surgical treatment of hallux rigidus with percutaneous Watermann-Moberg technique

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Abstract

Objective: Evaluate patients with hallux rigidus grades 1 and 2 by Coughlin and Shurnas classification, operated in two medical centers using an association of Watermann-Moberg osteotomies and cheilectomy by minimally invasive technique. In addition, evaluate clinical and functional parameters in the pre-and postoperative, using The American Orthopaedic Foot & Ankle Society (AOFAS) questionnaire and visual analog scale (VAS).

Methods: Twenty-five patients, 28 feet, hallux rigidus with grades 1 and 2, were operated on from July 2014 to December 2023. The AOFAS and VAS questionnaires were applied in the pre-and postoperative, with a minimum follow-up of six months.

Results: The preoperative AOFAS score was 41.18 (± 12.45) and 80.71 (± 12.01) in the postoperative, with a mean variation of 39.53 (± 14.68) ($p < 0.001$). Preoperative VAS was 7.61 (± 2.29) and 2.68 (± 2.86) in the postoperative, with a mean variation of 4.92 (± 3.75) ($p < 0.001$).

Conclusion: The combination of Watermann-Moberg percutaneous osteotomies showed a significant increase in the mean AOFAS score postoperatively compared to preoperatively. The mean VAS score postoperatively also showed a significant improvement in the level of pain presented by the patients included in the study. When properly indicated, the Watermann-Moberg percutaneous surgical technique is a safe and reliable option for treating hallux rigidus grades 1 and 2.

Level of evidence IV; Therapeutics studies, Case series.

Keywords: Hallux rigidus; Minimally invasive surgery; Surveys and questionnaires; Osteotomy.

Introduction

Hallux rigidus had its first descriptions in literature in the late nineteenth century. Davies-Colley[1] described it as hallux flexus in 1887, and Cotterill[2], in 1888, named it "hallux rigidus", a term still used today. Initially, it was characterized as a flexion deformity of the first metatarsal and a limitation of the extension of the first metatarsophalangeal joint (MTF)[3].

Its presentation follows a well-described pattern in which a dorsal osteophyte in the head of the first metatarsal is visualized radiographically, which can be palpable and cause discomfort when wearing shoes[4]. Clinically, the patient usually complains of pain when mobilizing the first MTF at the end of its flexion-extension, with progressive worsening of the pain and limitation of the range of motion of this joint[3,4].

Hallux rigidus has a multifactorial etiology and may be linked to family history, local trauma (recurrent microtraumas or intra-articular fractures), and anatomical changes (such as hallux valgus, first ray hypermobility, metatarsus primus elevatus, equine foot, and flat foot)[4,5].

The treatment of this condition begins conservatively, using measures such as analgesia, cryotherapy, physiotherapy, shoe adaptation, use of orthoses, and/or intra-articular

Study performed at the Hospital Municipal Universitário de Taubaté, Taubaté, SP, Brazil.

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infiltrations[6,7]. Surgical intervention is indicated for cases that are unresponsive to conservative treatment or directly indicated for moderate and severe cases[8,9]. Among the available surgical procedures are cheilectomy, osteotomies of the first proximal phalanx and the first metatarsal, resection of the proximal third of the first phalanx, resection arthroplasties, interposition and replacement, resurfacing and arthrodesis of the first MTF[9]. More recently, minimally invasive surgical (MIS) techniques have emerged as a treatment option for hallux rigidus, offering advantages such as reduced postoperative pain, early ambulation, lower infection rates, and the ability to perform the procedure under locoregional anesthesia[10].

The objective of this study is to evaluate patients with hallux rigidus grades 1 and 2, by Coughlin and Shurnas classification, operated in two medical centers using an association of Watermann-Moberg osteotomies and cheilectomy by minimally invasive technique. In addition, evaluate clinical and functional parameters in the pre-and postoperative, using The American Orthopaedic Foot & Ankle Society (AOFAS) questionnaire and visual analog scale (VAS).

Methods

This study was approved by the Institutional Review Board. All participating patients signed the Informed Consent Form, a mandatory criterion for participation in the study.

Twenty-five patients with hallux rigidus were operated on from July 2014 to December 2023, totaling 28 feet. The surgeries were performed in two medical centers. The patients were submitted to the percutaneous MIS technique, in which it was performed cheilectomy, osteotomy of the first metatarsal (Waterman technique), and osteotomy of the first proximal phalanx (Moberg technique), according to de Prado et al.[11].

Patients with symptomatic conditions were included, assessed by Coughlin and Shurnas classification grades 1 and 2 (Figure 1), with a minimum of six months of conservative treatment with physiotherapy, analgesia, and adequate footwear. Patients with hallux rigidus grades 3 and 4, rheumatoid arthritis, neurological feet, sequelae of fractures, and those submitted to previous surgery on the first ray were excluded.

Figure 1. Anteroposterior, lateral, and oblique preoperative radiographs of a patient classified as grade 2 by Coughlin and Shurnas classification.

The AOFAS and VAS questionnaires were collected in the pre-and postoperative, with a minimum follow-up time of six months. These data were analyzed to determine whether or not functional and pain improvement occurred. All questionnaires were administered by specialist foot and ankle surgeons.

Surgical technique

All procedures were performed by a team of two orthopedists specialized in foot and ankle surgery. The patients were positioned in horizontal dorsal decubitus, with their feet out of the operating table, without a tourniquet. They underwent locoregional anesthesia (penta-block) at the ankle.

Special materials were used for the surgeries, including the MIS beaver 64 scalpel blade, Wedge 4.1mm cutter, long Shannon cutter, and shavings, using a 6000 rpm drill motor.

All patients were submitted to percutaneous surgical techniques consisting of cheilectomy, osteotomy of the first metatarsal (Waterman technique), and osteotomy of the first proximal phalanx (Moberg technique).

Cheilectomy: A 5 mm incision was made on the medial surface at the transition from dorsal to plantar skin of the first metatarsal, proximal and dorsal to the sesamoid. This perpendicular incision was performed on the skin through the capsule towards the bone. A rasp was used in a dorsal and plantar direction, detaching the entire capsule and creating a space between the bone and the capsule to perform oscillatory movements. Then, the cutter was introduced, and with a 6000 rpm motor, the exostosis was thinned with oscillatory movements to the desired level. The entire procedure was performed using fluoroscopy guidance. The bone fragments were removed by expressing the operative wound, followed by thorough irrigation with saline. The removal of the dorsal spur, when present, was also sought during cheilectomy.

Osteotomy of the first metatarsal: A dorsal base wedge osteotomy was performed using the same anterior route, preserving the plantar cortical, aiming to decompress the MTP joint by extending the head of the first metatarsal.

Osteotomy of the first proximal phalanx: As the last step of the procedure, a 2-3 mm dorsomedial incision was made, through which we introduced the cutter through the medial portion of the first phalanx, crossing the lateral cortical and making a dorsal base wedge, followed by the closing of this wedge, shown in Figure 2. These procedures aim to allow an MTP extension of at least 70°. Synthesis material was not routinely used.

Postoperative: Patients were released for weight-bearing using rigid sole sandals from the first postoperative day. The dressing aims to maintain the immobilization of the first metatarsal and phalanx osteotomies, stabilizing even the neighboring toes. The immobilization was changed weekly by the surgical team until the fourth week, after the patients were instructed to change the immobilization at home every 3-4 days until the eighth week, when control radiographs were performed to show consolidation (Figure 3). Patients were then released from wearing the stiff-sole sandal.

Figure 2. Intraoperative radiography, showing the osteotomy performed by the Waterman and Moberg technique performed on the patient in Figure 1.

Figure 3. Postoperative radiographs (5 months) in anteroposterior, lateral, and oblique of the same patient.

Statistics

Clinical and functional evaluations were performed using the following pre- and postoperative parameters:

- AOFAS score for hallux: assessed functionality, pain, joint alignment, and range of motion (MTP flexion and extension).
- VAS quantified the pain on a scale of 0 to 10.

The data were analyzed descriptively. For categorical variables, absolute and relative frequencies (complications, sex, laterality) were presented. For the numerical variables (quantitative results of each parameter), summary measures (means and standard deviation) were used.

The Shapiro-Wilk test was used to evaluate the normality of the data. After confirming the normality of the data, it was decided to use the Student's T test to compare the variables AOFAS and VAS in the pre-and postoperative, evaluating the functional and clinical improvement. The significance level was set at $p < 0.05$.

Results

The sample consisted of 25 patients (28 feet). The mean age was 55.6 years, with a minimum age of 31 years and a maximum of 76 years. Nineteen (76.0%) patients were female, and six (24.0%) were male. Among the cases, 22 (88.0%) were approached unilaterally and 3 (12.0%) bilaterally. As for laterality, 14 were (50.0%) right feet, and 14 (50.0%) left.

Table 1. Paired sample statistics

		Mean	N	SD	Mean standard error
AOFAS	preop	41.18	28	12.455	2.354
	postop	80.71	28	12.018	2.271
VAS	preop	7.61	28	2.299	0.434
	postop	2.68	28	2.868	0.542

SD: Standard deviation; AOFAS: Forefoot score of the American Ortthopaedic Foot & Ankle Society; VAS: Visual analog scale.

The minimum postoperative follow-up time was six months and a maximum of 125 months, with a mean of 43.2 months, and of these, only five cases had a follow-up of less than 12 months.

The preoperative AOFAS score was 41.18 (± 12.45) and 80.71 (± 12.01) in the postoperative, with a mean variation of 39.53 (± 14.68) ($p < 0.001$).

Preoperative VAS was 7.61 (± 2.29) and 2.68 (± 2.86) in the postoperative, with a mean variation of 4.92 (± 3.75) ($p < 0.001$), as shown in Tables 1 and 2.

The results and their categorical and numerical variables are shown in Tables 3 to 7.

As complications related to surgical procedures, it was observed two cases of temporary hypoesthesia in hallux (7.1%), one case of prolonged edema (3.5%), one case of complex regional pain syndrome (3.5%), without improvement of preoperative pain, and one case of pain (3.5%) when submitted to exertion, totaling five complications (17.8%).

Discussion

In the literature, few published studies were found with significant casuistry showing surgical correction of hallux rigidus grades 1 and 2 using the MIS technique.

The mean AOFAS scores showed a significant increase (comparing the preoperative with the postoperative), as verified in the study by Arruda e Baptista[12] and Del Vecchio et al.[13], with surgical treatment by percutaneous technique, also implying an improvement in the MTP joint function. Also, the VAS scores demonstrated considerable improvement in the presence of pain, as noted by Arruda e Baptista[12], allowing patients to return to occupational and recreational activities with little or no restriction.

Osteotomies were performed to reposition the articular faces of the first metatarsal and proximal phalanx of the hallux, causing the articular cartilages, in better condition, to come into contact.

Cullen et al.[14], in their study comparing 341 feet that underwent isolated cheilectomy and 82 feet that underwent cheilectomy combined with osteotomy, reported a surgical revision rate of 8.21% in the isolated cheilectomy group vs.

Table 2. Paired specimen testing

		Mean	SD	Mean standard error	95% confidence interval		t-student	df	Significance (2 extremities)
					Inferior	Superior			
AOFAS	preop postop	-39.536	14.686	2.775	-45.230	-33.841	-14.246	27	0.000
VAS	preop postop	4.929	3.751	0.709	3.474	6.383	6.953	27	0.000

SD: Standard deviation; AOFAS: Forefoot score of the American Ortthopaedic Foot & Ankle Society; VAS: Visual analog scale.

Table 3. Paired sample statistics[a]

		Mean	N	SD	Mean standard error
AOFAS	preop	38.86	21	12.823	2.798
	postop	80.90	21	12.653	2.761
VAS	preop	7.81	21	2.442	0.533
	postop	2.81	21	2.857	0.623

[a]Sex = 1(female).
SD: Standard deviation; AOFAS: Forefoot score of the American Ortthopaedic Foot & Ankle Society; VAS: Visual analog scale.

Table 4. Paired specimen testing[a]

		Mean	SD	Mean standard error	95% confidence interval		t-student	df	Significance (2 extremities)
					Inferior	Superior			
AOFAS	preop postop	-42.048	13.757	3.002	-48.310	-35.786	-14.007	20	0.000
VAS	preop postop	5.000	3.834	0.837	3.255	6.745	5.976	20	0.000

[a]Sex = 1(female).
SD: Standard deviation; AOFAS: Forefoot score of the American Ortthopaedic Foot & Ankle Society; VAS: Visual analog scale.

Table 5. Paired sample statistics[a]

		Mean	N	SD	Mean standard error
AOFAS	preop	48.14	7	8.630	3.262
	postop	80.14	7	10.761	4.067
VAS	preop	7.00	7	1.826	0.690
	postop	2.29	7	3.094	1.169

[a]Sex = 2 (male).
SD: Standard deviation; AOFAS: Forefoot score of the American Ortthopaedic Foot & Ankle Society; VAS: Visual analog scale.

Table 6. Paired specimen testing[a]

		Mean	SD	Mean standard error	95% confidence interval		t-student	df	Significance (2 extremities)
					Inferior	Superior			
AOFAS	preop postop	-32.000	15.853	5.992	-46.662	-17.338	-5.340	6	0.002
VAS	preop postop	4.714	3.773	1.426	1.225	8.204	3.306	6	0.016

[a]Sex = 2 (male).
SD: Standard deviation; AOFAS: Forefoot score of the American Ortthopaedic Foot & Ankle Society; VAS: Visual analog scale.

Table 7. Correlations

		Age	Follow-up (months)	Extension postop (degree)	Flexion postop (degree)
Age	Pearson correlation	1	-0.084	-0.076	-0.252
	Significance (2 extremities)		0.672	0.701	0.195
	N	28	28	28	28
Follow-up (months)	Pearson correlation	-0.084	1	-0.216	-.418*
	Significance (2 extremities)	0.672		0.270	0.027
	N	28	28	28	28
Extension postop (degree)	Pearson correlation	-0.076	-0.216	1	0.368
	Significance (2 extremities)	0.701	0.270		0.054
	N	28	28	28	28
Flexion postop (degree)	Pearson correlation	-0.252	-.418*	0.368	1
	Significance (2 extremities)	0.195	0.027	0.054	
	N	28	28	28	28

*. The correlation is significant at the 0.05 level (2 extremities).

only 1.22% in the combined procedure group. These findings suggest that osteotomy of the phalanx and metatarsal contributes to improved outcomes.

Monteiro et al.[15] performed open surgical treatment of hallux rigidus grade 2 with cheilectomy associated with the fixed Moberg technique and also showed good results.

Teoh et al.[16] performed isolated cheilectomy by MIS technique in 89 patients and had two cases of infections and two surgical wound healing delays, unlike what was found in our study, in which we did not have any cases of these complications.

It was noted that there was a need to indicate phalangeal metatarsal arthrodesis in only one case due to the persistence of pain. On the other hand, Teoh et al.[16] reopened 12 feet, and arthrodesis was performed in seven.

Unlike other studies, there was no injury to the extensor hallucis longus and the dorsal medial cutaneous nerve of the hallux[16-18].

The complication rate in our study (17.8%, five cases) corroborates other studies of MIS surgery for mild to moderate cases of hallux rigidus, showing to be a safe and effective technique when well indicated and performed by a qualified professional[13,16,17].

A limitation of our study is that we did not analyze the isolated mobility of the MTF joint using degree measurements preoperatively and postoperatively. However, the AOFAS score was utilized to assess joint mobility in one of its items, and no severe joint limitations were identified.

Despite the long follow-up period of this study, it was observed that our sample is small due to the low indication of surgical treatment for hallux rigidus grades 1 and 2, which limits a better evaluation of osteotomies and cheilectomy.

Conclusion

The combination of Watermann-Moberg percutaneous osteotomies showed a significant increase in the mean AOFAS score postoperatively compared to preoperatively. The mean VAS score postoperatively also showed a significant improvement in the level of pain presented by the patients included in the study. When properly indicated, the Watermann-Moberg percutaneous surgical technique is a safe and reliable option for treating hallux rigidus grades 1 and 2.

Author's contributions: Each author contributed individually and significantly to the development of this article: LCRL* (https://orcid.org/0000-0003-1158-2643) 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, bibliographic review, survey of the medical records, clinical examination, approved the final version; GB* (https://orcid.org/0000-0001-5273-4303) Conceived and planned the activities that led to the study, participated in the review process, performed the surgeries, formatting of the article, approved the final version; LFL *(https://orcid.org/0000-0003-1048-7134) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, performed the surgeries, approved the final version; FPL *(https://orcid.org/0000-0002-9888-5614) Participated in the review process, performed the surgeries, bibliographic review, formatting of the article; NRX *(https://orcid.org/0009-0005-9113-3902) Interpreted the results of the study, participated in the review process, performed the surgeries, formatting of the article; LTSC *(https://orcid.org/0009-0000-1870-352X) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, data collection, bibliographic review, survey of the medical records, formatting of the article, clinical examination; VCL *(https://orcid.org/0009-0000-1762-5654) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, statistical analysis, bibliographic review, formatting of the article; LFGM *(https://orcid.org/0009-0001-7596-5945v) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, statistical analysis, bibliographic review, formatting of the article; NPB *(https://orcid.org/0009-0006-8659-0081) Interpreted the results of the study, participated in the review process, bibliographic review, formatting of the article; GARV *(https://orcid.org/0009-0001-1903-3289) Data collection, survey of the medical records, clinical examination. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID)Surgical treatment of hallux rigidus with percutaneous Watermann-Moberg technique iD.

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Original Article

Epidemiological study of posterior malleolus fractures

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Abstract

Objective: Perform an epidemiological analysis of patients who suffered ankle fractures, including the posterior malleolus.

Methods: Data were collected from 123 consecutive patients who suffered ankle fractures affecting the posterior malleolus between October 2021 and November 2023 in one institution. Skeletally immature patients or patients with incomplete radiological exams were excluded, including a final sample of 100 patients. The parameters analyzed were sex, age, side, comorbidities, mechanism of trauma, and associated injuries. In addition, fractures were evaluated according to Danis-Weber and Bartoníček classifications.

Results: Posterior malleolus fractures were more present in females on the right side and in the 5th decade of life, and comorbidities were observed in 46% of patients. The most frequent trauma mechanism was ankle sprain at ground level, and the main associated injury was tibial shaft fracture. The most frequent posterior malleolus fractures were Bartoníček type 2 and fibular fractures, Danis-Weber type B.

Conclusion: Posterior malleolus fractures occurred predominantly in females in the 5th decade of life, after ankle sprains, Bartoníček type 2. Hypertension was the most prevalent comorbidity, and the most common associated fracture was transindesmal fractures of the fibula (Danis-Weber B).

Level of evidence IV, Therapeutic studies, Case series.

Keywords: Epidemiology; Ankle fractures.

Introduction

Ankle fractures are the fifth most common fracture in adults, with an incidence of approximately 1,000 cases per 1 million people per year[1]. Posterior malleolus fracture (PMF) is still a topic of discussion, with divergences in the literature from its epidemiology to treatment. The increased use of computed tomography (CT) in diagnosing ankle fractures has enhanced the diagnosis of PMF and provided a deeper understanding of fracture patterns and their management[2].

Isolated PMFs are rare and are commonly associated with other ankle injuries, such as fractures of the medial and lateral malleolus[3]. The involvement of the posterior malleolus (PM) is considered a factor of worse prognosis in these fractures, which can evolve with serious complications such as chronic pain, joint stiffness, and, ultimately, post-traumatic osteoarthritis[1].

Epidemiological studies on fractures contribute to the organization of trauma services and the development of effective strategies for prevention and treatment[4]. Epidemiological studies of PMF are scarce and contradictory, with a wide variation in incidence between studies[5]. Previous studies describe a frequency of 7% to 44% of PM involvement in ankle fractures[6]. As a result, the epidemiological profile of PMF remains visibly incomplete.

The objective of this study is to perform an epidemiological analysis of patients who suffered ankle fractures, including the posterior malleolus, expanding the current concepts present in the literature.

Methods

This is a cross-sectional epidemiological study in which data were collected from 123 consecutive patients who suffered ankle fractures affecting the PM between October 2021 and November 2023 in one institution. Skeletally immature patients or patients with incomplete radiological exams were excluded, including a final sample of 100 patients.

Study performed at the Santa Helena Hospital, Brasília, DF, Brazil.

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The parameters analyzed were sex, age, side, comorbidities, mechanism of trauma, and associated injuries. Fractures were evaluated according to Danis-Weber[7,8] and Bartoníček et al.[9] classifications regarding the fracture pattern of the lateral malleolus and posterior malleolus, respectively. The model proposed by Danis-Weber divides fibular fractures into A (infrasyndesmal), B (transsyndesmal), and C (suprasyndesmal). The model proposed by Bartoníček classifies PMF into type 1 (extrafibular notch fragment), type 2 (posterolateral fragment extending into the fibular notch), type 3 (posteromedial two-part fragment involving the medial malleolus), type 4 (large posterolateral triangular fragment) and type 5 (irregular, osteoporotic fragments, not classifiable in the previous types).

Information on the physical examination, surgery details, procedure complexity, and rehabilitation protocol was not available in the database.

The calculated descriptive statistics were means and standard deviation (SD) for continuous variables and frequency and percentages for discrete variables. All statistical analyses were performed using Excel 2021 spreadsheet.

Results

The majority of the 100 patients evaluated were female (68%), with a male-to-female ratio of 0.47. The mean age was 50.4 years (± 49.5), affecting mainly patients in the 5th decade of life, with the right side being affected in 58% of cases (Table 1).

In the sample, 46% had comorbidities, the most prevalent being hypertension (43.5%), psychiatric disorders (28.2%), dyslipidemia (23.9%) and Diabetes Mellitus (17.3%). The most frequent trauma mechanism was a ground-level sprain (63%), followed by falling down stairs (18%). Associated injuries were found in only 8% of cases, the most common being tibial shaft fracture in three cases (Tables 2 and 3).

Regarding the Danis-Weber classification, type B was the most prevalent (68%), followed by type C (25%). According to Bartoníček classification, type 2 was the most prevalent in 52% of cases, followed by type 3 in 29% of cases (Figures 1 and 2).

Discussion

Several studies reveal that ankle fractures involving the MP are frequent and are associated with worse clinical outcomes. However, studies investigating their epidemiological profile are still scarce[9,10-13]. In our study, the epidemiological evaluation of PMF was performed, and its main findings were the predominance of females, a mean age of 50.4 years, and comorbidities in 46% of patients. The most frequent trauma mechanism was ankle sprain at ground level, and the main associated injury was tibial shaft fracture. Finally, there was a higher prevalence of Danis-Weber type B in lateral malleolus fractures and Bartoníček type 2 in PMF.

The results of our study align with previous studies regarding the sex and age group most commonly affected. A predominance of females was observed, representing 68% of the sample, with a proportion of 0.47 among men and women, especially in the 5th decade of life. A recent epidemiological study by Li et al.[5], including 472 patients with PMF, also showed a higher predominance of females (53.4% of patients) and a peak incidence between 50-59 years. This higher prevalence in females is also observed when analyzing ankle fractures as a whole, with or without MP involvement. A previous study, including over 50,000 ankle fractures, showed that most ankle fractures affect women, corresponding to 61% of cases[12]. Another study also described a higher involvement of females and an association with the advancement of the age group[13]. Since older women have a higher incidence of osteopenia and osteoporosis, we can infer from the data presented that PMF may be related to bone fragility.

Table 1. Variables analyzed and their respective percentages

Variables	N = 100
Sex (M/F)	32 (32%) / 68 (68%)
Age	50.4 (± 49.5)
Side (R/L)	58% / 42%
Comorbidity (Yes/No)	54% / 46%
Associated injuries (Yes/No)	8% / 92%

Table 2. Comorbidities

Comorbidities	n (%)
Hypertension	20
Psychiatric disorders	13
Dyslipidemia	11
Diabetes	8
Hypothyroidism	5
Heart disease	5
Obesity	4
Intestinal cancer	2
Osteoporosis	2
Asthma	2
Migraine	2
Fibromyalgia	2
Others	8

Table 3. Trauma mechanism

Mechanism	n (%)
Ankle sprain at ground level	63
Fall down stairs	18
Sports	8
Motorcycle fall	4
Fall from height	3
Others	4

Comorbidities, especially in older patients, can impact the choice of PMF treatment and the results obtained[14]. A significant percentage of patients included in the study had associated comorbidities (46%). Cardiovascular diseases represent the majority of them, present in 36% of patients, followed by psychiatric diseases that had great relevance, affecting 13% of patients. Although mental illness was not directly associated with higher complication rates, Simske et al.[15] showed that patients with mental illness associated with ankle fractures had lower functionality and higher levels of postoperative pain. Diabetes was present in 8% of the cases evaluated, being a pathology known to be associated with increased rates of complications during the treatment of an ankle fracture[16]. Obesity was present in 4% of cases despite a relatively low incidence; a previous study[17] demonstrated a higher chance of obese patients suffering an ankle fracture, especially more unstable fractures, types B and C of Danis-Weber. The high number of patients with comorbidities observed in the study highlights the need for a careful preoperative evaluation and careful postoperative follow-up since these patients may have higher rates of complications, especially in severe fractures such as trimalleolar fractures.

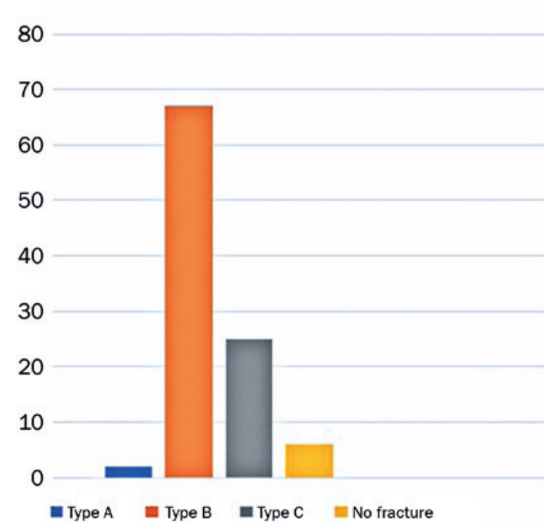

Figure 1. Distribution of peroneal fractures, according to the Danis-Weber classification.

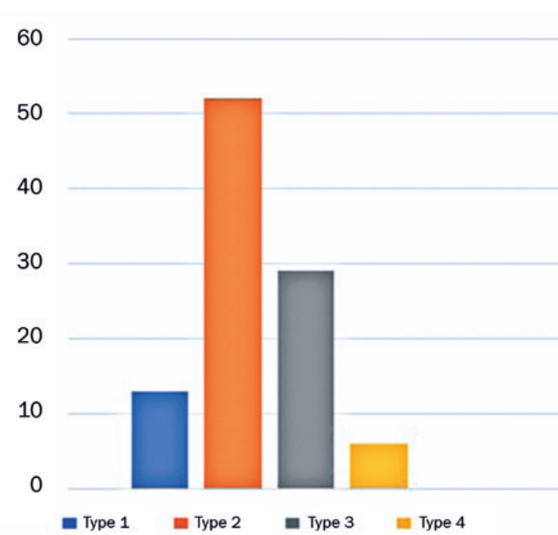

Figure 2. Distribution of posterior malleolus fractures, according to Bartoníček classification.

Approximately 20% of ankle fractures are secondary to injuries with external rotation of the talus, often involving the posterior malleolus. In our study, it was observed that in 63% of cases, PMF was due to a sprain that occurred at ground level, followed by 18% of cases caused by falling down stairs. Li et al.[5] presented similar results, with sprain being the main mechanism of PMF trauma, accounting for 86.5% of the cases. These data are similar to those found in ankle fractures in general, in which falls at ground level are the main trauma mechanism[12,18]. In addition, only 8% of the patients in our study had associated injuries, the most common being the diaphyseal fracture of the ipsilateral tibia (4% of the cases). Previous studies show this association, often emphasizing that associated injuries are underdiagnosed, partly due to the lack of TC evaluation[19]. These data reinforce the need for a complete radiological analysis to diagnose PMF, allowing for a more appropriate treatment.

Isolated PMFs are rare and are commonly associated with other ankle injuries, such as fractures of the medial and lateral malleolus. To better characterize PMF, the lateral malleolus fractures were classified using the Danis-Weber classification. The majority of cases were type B (68%) and C (25%), a statistical result similar to that presented by Bartoníček et al.[9]. Interestingly, we observed a few cases (6%) without an associated fibula fracture, as well as a single instance of a type A fracture. Regarding the Bartoníček classification, it was possible to classify all cases between types 1 to 4. Types 2 and 3 were the most frequent, representing 52% and 29% of cases, respectively. These statistics are similar to those obtained by Rammelt et al.[3] in their initial study, with 141 cases (Type 2 (52%), type 3 (28%), type 4 (9%) and type 1 (8%)), but with discrepancy between the frequencies of types 4 and 1. In the study by Li et al.[5], which used the classification proposed by Haraguchi et al.[20], the authors presented an incidence of 78.2% of posterolateral fractures (equivalent to Bartoníček's type 2), 10.4% of fractures with medial extension (equivalent to Bartoníček's type 3) and 11.4% of fractures with small extra-incisural fragment (equivalent to Bartoníček's type 1). These results are statistically similar to the pre-existing epidemiological data, but considering the relatively small sample, the previous literature, and the variations observed, larger studies are needed to consolidate this information.

Our study has numerous limitations, many of which are intrinsically related to the study design. Among them, we highlight that this is a single-center study, the sample size is small, and there is a lack of evaluation of the treatment and prognosis of fractures. Further studies analyzing these aspects will certainly expand the knowledge about PMF.

Conclusion

Posterior malleolus fractures occurred predominantly in females on the right side and in the 5th decade of life, and the comorbidities were observed in 46% of patients. The most frequent trauma mechanism was ankle sprain at ground level, and the main associated injury was tibial shaft fracture. The most frequent PMF was posterolateral with involvement of the fibular notch (Bartoníček type 2) the most common associated fracture was transindesmal fractures of the fibula (Danis-Weber B).

Authors' contributions: Each author contributed individually and significantly to the development of this article: SPO *(https://orcid.org/0000-0002-5649-8122) Conceived and planned the activities that led to the study; BASA *(https://orcid.org/0000-0001-5269-9106) Interpreted the results of the study, participated in the review process; HM *(https://orcid.org/0000-0001-7527-969X) Participated in the review process. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Original Article

Arthroscopic ankle arthrodesis: clinical results

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Abstract

Objective: To evaluate the clinical outcome of arthroscopic ankle arthrodesis.

Methods: This is a retrospective study involving 17 patients with ankle arthritis who showed no improvement with conservative treatment. Patients underwent ankle arthrodesis via ankle arthroscopy between January 2015 and December 2020, all performed by the same surgeon. The American Orthopaedic Foot and Ankle Society (AOFAS) ankle-hindfoot score was used for functional assessment of patients, while patient satisfaction and quality of life was assessed by the Patient-Reported Outcomes Measurement Information System (PROMIS Global – 10), with maximum of 20 points per evaluated item.

Results: Average surgery time was 81.4 ± 7.9 minutes, and all patients were discharged on the day following surgery. Average time for consolidative arthrodesis was 10.8 ± 1.9 weeks. The preoperative AOFAS ankle-hindfoot score showed a statistically significant improvement when compared to that obtained at the last consultation (from 55.8 ± 3.2 to 89 ± 2.1). The physical status measured by PROMIS preoperatively increased from 9.8 ± 1.2 to 18.2 ± 1.3, just as mental health increased from 8.9 ± 1.1 to 17.9 ± 1.5.

Conclusion: Ankle arthrodesis through arthroscopy is a less invasive option that has shown significant improvement in the AOFAS ankle-hindfoot and PROMIS scores, with a high union rate.

Level of evidence Level IV; Therapeutic studies; Case series.

Keywords: Arthroscopy; Ankle; Arthrodesis.

Introduction

Despite the increased popularity of total ankle arthroplasty, arthrodesis still remains the gold standard surgical treatment for end-stage osteoarthritis[1].

For a long time, ankle arthrodesis was performed using different approaches, such as lateral (transfibular), anterior, medial, and mini-arthrotomy. The open approach facilitates alignment corrections, plate fixation, and bone graft placement; however, it is aggressive and has considerable complication rates[2].

Arthroscopic arthrodesis has been a choice among foot and ankle surgeons who prefer less invasive procedures. Schneider was the first to demonstrate that this option results in less morbidity, shorter consolidation time, and faster mobility[3]. Published studies have shown that arthroscopic arthrodesis, when compared to the open approach, reduced recovery and hospitalization time, accelerated consolidation time, and reduced soft tissue complications[2,4,5].

The aim of this retrospective study is to present results obtained through arthroscopic ankle arthrodesis in a group of 17 patients in a short-term follow-up.

Methods

The work developed was approved by the ethics committee, being registered on Plataforma Brasil under opinion number 6.417.805.

This is a retrospective study involving 17 patients with ankle arthritis who did not show improvement with conservative treatment. Patients underwent ankle arthrodesis via ankle arthroscopy between January 2015 and December 2020, all performed by the same surgeon.

Study performed at the Hospital Universitário Evangélico Mackenzie, Curitiba, PR, Brazil.

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Inclusion criteria were failure of conservative treatment for six months, deformity of less than 10 degrees in the coronal plane, and no active infection in the ankle. Exclusion criteria were patients with less than two years of follow-up, patients without pre- and postoperative radiographs, osteoarthritis in adjacent joints, and patients undergoing other associated procedures in the foot and ankle.

The American Orthopaedic Foot and Ankle Society (AOFAS) ankle-hindfoot score was used for functional assessment of patients, while patient satisfaction and quality of life was assessed by the Patient-Reported Outcomes Measurement Information System (PROMIS Global – 10), with a maximum of 20 points per evaluated item.

The procedure duration and the time for arthrodesis to consolidate were evaluated.

Preoperatively, 1 g of intravenous cephalosporin was administered. All procedures were performed by the same surgeon, with patients under spinal anesthesia. A thigh tourniquet with a pressure of 350 mmHg was applied.

Standard anteromedial portal was used, and the anterolateral portal was established under arthroscopic vision. Large joint power shavers and a 4.0 mm arthroscope were used. We did not use any ankle distractor.

The cartilage covering the tibial plafond and the talus dome, the hypertrophic synovium, fibrosis, or any loose bodies were aggressively debrided with the aid of a motorized shaver blade with a 3.5 mm radius. In addition, a curette was inserted to aggressively remove any remaining articular cartilage. A 4.0-mm full-radius burr was then used to remove the subchondral plate to the level of viable bleeding bone. Crossed 7.0 mm partially-threaded steel cannulated screws were used-one screw placed from the medial side and one screw placed from the lateral side for fixation under the guidance of a C-arm image intensifier. Where there was a varus talar tilt, we started from medial screw; where there was a valgus talar tilt, we started from lateral screw. Both screws were angled to advance down to the body of the talus (starting 30 mm above the tibial plafond), avoiding penetration of the subtalar joint with the foot aligned in neutral position (90 degrees) dorsiflexion, neutral varus-valgus, and neutral rotation (Figure 1). Portals and stab incisions for screw placement were closed with simple sutures.

Bulky compressive dressing and posterior plaster splint were applied for six to eight weeks.

Partial weight bearing in a walker splint was permitted after radiographic appearance of bridging trabeculae. Full weight bearing was allowed after two months.

Statistical analysis

Initially, all data were analyzed for normality of distribution using the Kolmogorov-Smirnov test (KS test). Numerical values were presented as means and standard deviations, with a 95% confidence interval. The difference between the preoperative and postoperative means of the AOFAS and PROMIS scores was estimated using paired t-test. A $p < 0.05$ indicated statistical significance for all tests. Post hoc analysis indicated that statistical power was 96.3% for an alpha error of 0.05 and a large size difference made for the two dependent

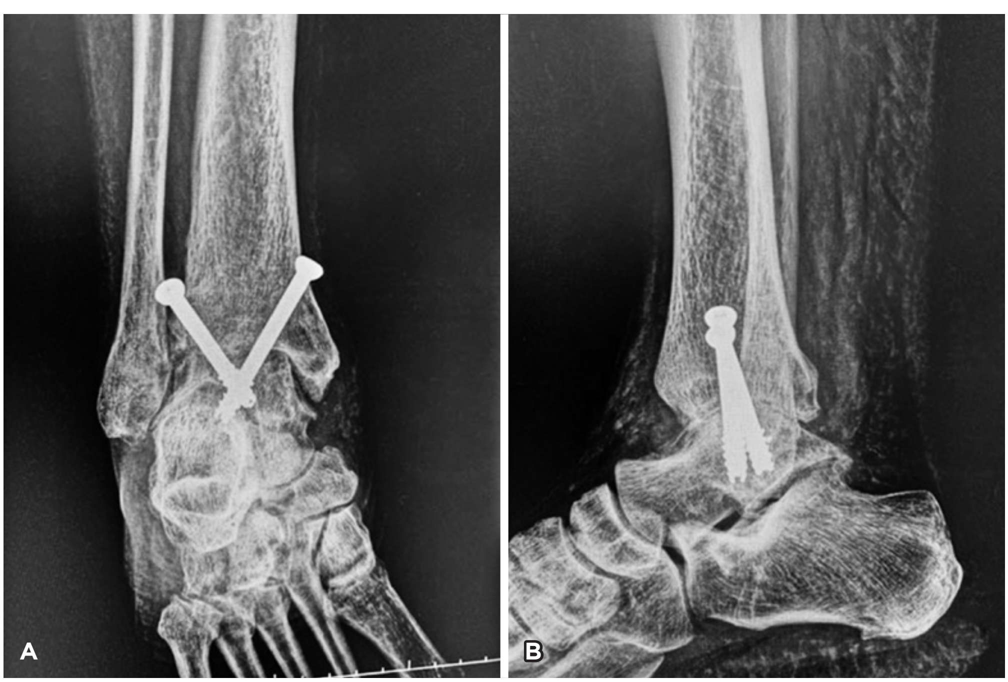

Figure 1. (A) anteroposterior view; (B) lateral view.

means using G*Power version 3.1. For statistical analysis, the Statistical Package for Social Sciences (IBM, version 16.0, Inc, Chicago, IL) was used.

Results

We analyzed 17 patients who underwent arthroscopic ankle arthrodesis (Table 1).

Mean age was 39.6 ± 4.1, and the follow-up was, on average, at 34.3 ± 3.1 months. One case of superficial surgical wound infection treated with oral antibiotics was observed, without other serious complications. There was no nonunion, implant failure, or arthrosis in underlying joints.

Average surgery time was 81.4 ± 7.9 minutes, and all patients were discharged on the day following surgery.

Average time for consolidative arthrodesis was 10.8 ± 1.9 weeks.

The preoperative AOFAS ankle-hindfoot score showed a statistically significant improvement when compared to that obtained at the last consultation (from 55.8 ± 3.2 to 89 ± 2.1, Table 2).

The physical status measured by PROMIS preoperatively increased from 9.8 ± 1.2 to 18.2 ± 1.3; just as mental health increased from 15.9 ± 1.1 to 17.9 ± 1.5 (Table 2).

At the end of follow-up, patients were satisfied with the surgery and returned to work in 20.8 ± 3.3 weeks.

Discussion

Ankle arthrodesis through arthroscopy has been studied over the years and has shown good postoperative results. Advantages, such as shorter time for consolidation, shorter hospital stay, similar consolidation rate, and less pain, have been observed when compared to the open procedure[6].

All patients evaluated in our study progressed to consolidation of ankle arthrodesis, which was confirmed by X ray and clinical findings.

This result is comparable to those obtained by Peterson et al.[7]. One of the concerns of the surgeon responsible for the surgeries in our study was to remove all tibiotarsal cartilage and perform several deepenings in the subchondral bone. After these steps, the tourniquet is released to verify

Table 1. Patients analyzed

Name	Preoperative AOFAS	Postoperative AOFAS	Preoperative PROMIS	Postoperative PROMIS
Patient 1	52	87	8	15
Patient 2	54	91	9	19
Patient 3	59	85	8	16
Patient 4	55	83	9	19
Patient 5	57	84	10	16
Patient 6	55	85	11	17
Patient 7	56	86	10	18
Patient 8	57	87	9	16
Patient 9	58	88	8	17
Patient 10	59	89	9	15
Patient 11	54	90	9	17
Patient 12	53	91	12	18
Patient 13	53	90	11	17
Patient 14	52	88	11	16
Patient 15	55	89	8	17
Patient 16	57	86	9	16
Patient 17	58	85	11	14

Table 2. Pre- and postoperative AOFAS and PROMIS scores

	Pre-op mean	Pre-op 95% CI	Final post-op mean	Final post- op 95% CI	p-value
AOFAS	55.8 ± 3.2	53.1–57.6	89 ± 2.1	87–90.1	<0.00001
PROMIS					
Physical health	9.8 ± 1.2	9.6–11.1	18.2 ± 1.3	17.1–18.7	<0.00001
Mental health	8.9 ± 1.1	8.1–9.8	17.9 ± 1.5	17.1–18.2	<0.00001

CI: confidence interval; AFOAS: American Orthopaedic Foot and Ankle Society; PROMIS: Patient-Reported Outcomes Measurement Information System. A $p < 0.01$ indicates a significant result.

bone bleeding from the distal tibia and talus. We believe this care was crucial for consolidation in the studied cases. Furthermore, arthroscopy preserves the soft tissues, leading to less damage to the vascularization of the ankle and thus favoring the arthrodesis consolidation.

Average consolidation time was 10.8 ± 1.9 weeks. Several studies show a consolidation time of 9–12 weeks. Our result is similar to that found in the literature[8,9].

Average procedure duration was 81.4 ± 7.9 minutes. Such surgery time is shorter than that found in studies by Gougoulias et al.[10] (104 ± 35 minutes), Wang et al.[11] (140.5 ± 22.2 minutes), and Townshend et al.[12] (99 ± 16.4 minutes). Possibly, the cases included in our study were easier to articulate than those that took longer in other studies. Another possible justification is the surgeon responsible for the procedures in our study having over 10 years of experience in performing arthroscopy.

We found a significant increase in the AOFAS ankle-hindfoot score, which improved from 55.8 ± 3.2 to 89 ± 2.1, a result comparable to that found by Nielsen et al.[5] (AOFAS hindfoot and final ankle of 81.3 ± 3.7) and better than the findings of Wang et al.[11] (77.7 ± 3.8) and Woo et al.[13] (78.9 ± 18.9). This highlights the power of the procedure in improving patients' pain and functionality.

The limitation of our study is the small number of cases evaluated; a larger group is needed to increase statistical power. A control group would also be interesting to evaluate other treatment options and carry out a prospective study, given that ours is retrospective.

Conclusion

Ankle arthrodesis through arthroscopy is a less invasive option that has shown significant improvement in the AOFAS ankle-hindfoot and PROMIS scores, with a high union rate.

Authors' contributions: Each author contributed individually and significantly to the development of this article: BAMS *(https://orcid.org/0000-0002-3008-460X) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, performed the surgeries, clinical examination; JBV *(https://orcid.org/0000-0002-3025-4584) Data collection, statistical analysis, bibliographic review, survey of the medical records, formatting of the article; HLB *(https://orcid.org/0009-0008-8121-521X) Data collection, formatting of the article; PHST *(https://orcid.org/0009-0008-6742-6838) Data collection, statistical analysis, bibliographic review; RV *(https://orcid.org/0000-0001-5835-9153) Survey of the medical records, formatting of the article, clinical examination; LF *(https://orcid.org/0000-0002-6775-593X) Survey of the medical records formatting of the article. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Original Article

Bone spur formation in transtibial amputation in pediatric patients

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Abstract

Objective: Amputating a limb during childhood is a rare yet significant event often perceived as a catastrophe by families and subsequently by the child. A multidisciplinary team, including wound care, rehabilitation, and prosthesis fitting specialists, plays a crucial role in managing these patients. The objective of this study is to retrospectively evaluate transtibial amputations performed on children aiming to assess the percentage of individuals who developed symptomatic spurs after the initial amputation procedure.

Method: This study retrospectively evaluates transtibial amputations performed on children from 1990 to 2021, focusing on the development of symptomatic bone spurs post-surgery.

Results: Our findings indicate that out of 27 patients under 12 years of age, 66.66% developed symptomatic spurs requiring revision surgery, with a mean time to identify these spurs being approximately 53 months post-amputation. The primary indications for amputation were congenital issues (51.85%), trauma, and infections. Although bone overgrowth is the most common complication in 66.66% of cases, younger individuals are more likely to experience this issue. Despite the high revision rates, amputation remains critical for long-term functional outcomes. Limitations of the study include a small sample size and retrospective design, yet it highlights the importance of vigilance regarding bone spur formation in pediatric amputees.

Conclusion: Bone spurs are a common complication of transtibial amputation in children, regardless of the technique used for the procedure. Understanding the existence of this condition allows physicians to educate families and children about this possibility and prepare them for possible new procedures.

Level of evidence IV; Therapeutic studies - investigating the results of treatment.

Keywords: Amputation, surgical; Child; Osteophyte.

Introduction

Amputating a limb during childhood is a rare event that families often perceive as a catastrophe, followed by the child. The principles required to create a stump capable of accepting a prosthesis that restores function must be fully understood[1,2].

A multidisciplinary team, including wound care, rehabilitation, prosthesis selection and fitting, and social support specialists, plays a crucial role in managing these patients. Additionally, the orthopedic surgeon and other team members should collaborate to monitor the patient's development and growth, making decisions about prosthesis replacement and fitting[3,4].

Researchers and developers have made considerable advances in prosthetics in recent years. Experts have introduced new materials and prosthetic designs to improve performance and facilitate the child's adaptation to the prosthesis. These changes have prompted a re-evaluation of the principles underlying amputation surgery[2].

Study performed at the Faculdade de Medicina, Universidade de São Paulo, São Paulo, SP, Brazil.

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Transtibial amputation preserves the growth plate, and this can be considered an advantage of the procedure at this level since the amputated limb can follow the child's global development, generating a better proportion between the stump and the rest of the body. However, other theories attempt to explain these characteristics, such as the fact that in the immature skeleton, the characteristic of the periosteum causes it to move away from the end of the amputated stump and form the spurs. These bony prominences grow rapidly, creating a sharp and rigid formation that can penetrate overlying soft tissues, gradually increasing local pressure and leading to ulcerations and pain. This results in many surgical revisions for this reason[5-8] (Figures 1 and 2).

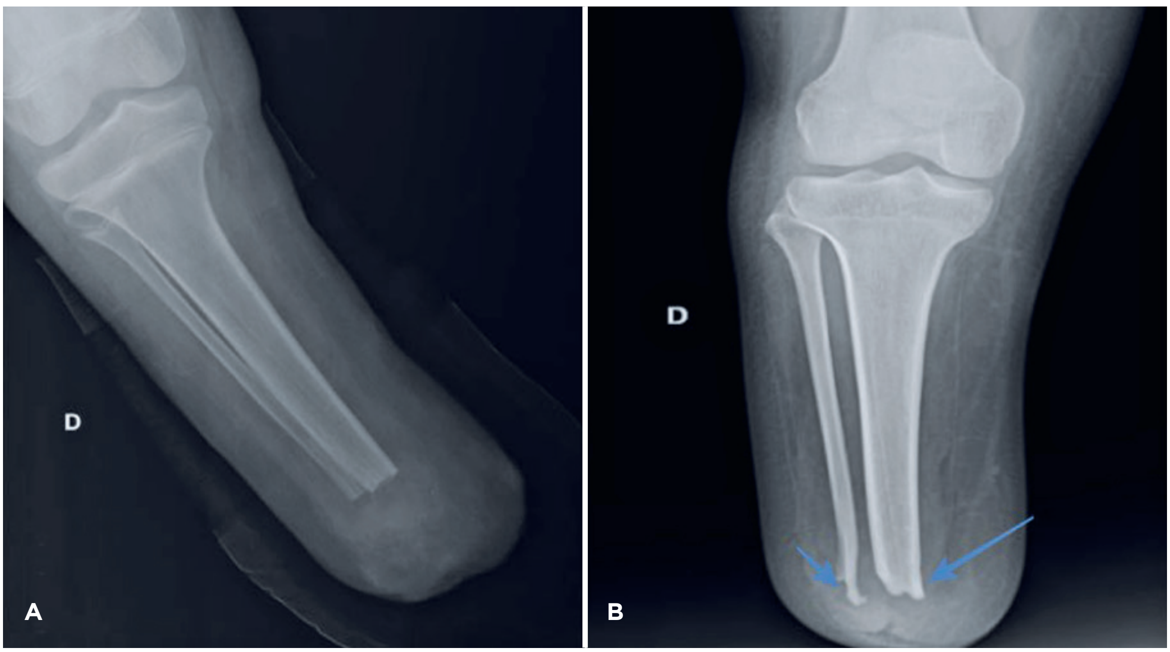

Figure 1. Radiographic images of the right transtibial amputation stump in a child. (A) The stump is shown immediately after the initial amputation procedure, with the proximal growth plates of the fibula and tibia open (B) 43 months postoperatively, prominent bone spurs (blue arrow) are visible at the distal end of the stump.

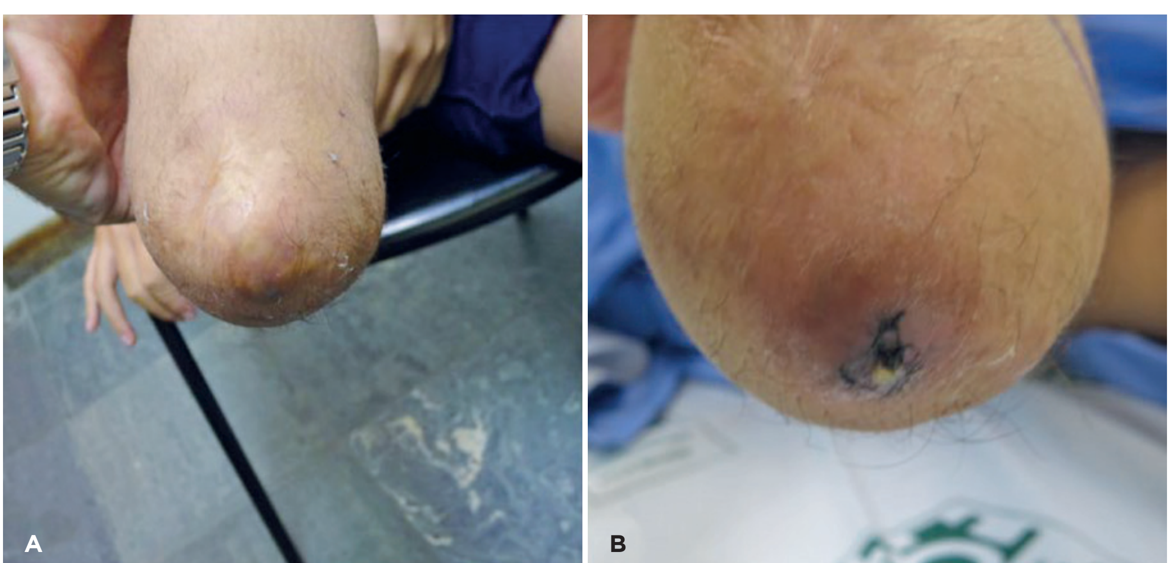

Figure 2. Image of the right transtibial amputation stump in a child. (A) The prominent stump shows an area of overload and a painful point (B) Several months later, ulceration is present with discharge and local signs of infection.

The objective of this study is to retrospectively evaluate transtibial amputations performed on children from 1990 to 2021, aiming to assess the percentage of individuals who developed symptomatic spurs after the initial amputation procedure.

The hypothesis is that a significant percentage of children submitted to transtibial amputation develop spurs and require further intervention.

Material and Method

The study was approved by the Institutional Review Board under the number 8398.6924.5.0000.0068. This is a retrospective case series with patients submitted to transtibial amputation before the age of 12 years old in one outpatient clinic.

The procedure consisted of transtibial amputation with the bone level defined by the location and characteristics of the deformity. Generally, the surgeon inflates the tourniquet in the thigh, makes a fish-mouth incision in the limb to be operated on, and performs dissection down to the bone level. After performing the tibia osteotomy, the fibula was cut more proximally, if present, and a periosteal bridge was created between the fibula and tibia. The surgeon ligates all arteries and veins and cuts the nerves with a new blade more proximally to avoid the formation of symptomatic neuromas in the stump. At this point, the tourniquet was released and checked for hemostasis. Then, myodesis and myoplasty procedures were performed, and the skin closure was also performed. Sterile dressings were applied to keep the stump rounded.

Data was collected through anamnesis, clinical examination, and imaging tests performed at the institute between 1990 and 2021.

The inclusion criteria were patients submitted to transtibial amputation surgery in our institute and also followed up at the outpatient clinic. The first surgery was performed on a patient under 12 years of age. The exclusion criteria were patients with a postoperative infection.

Epidemiological data, including sex, age, comorbidities, and clinical and imaging evolution, was collected in search of spur formation and the need to review the initial procedure.

Results

From 1990 to 2021, 27 transtibial amputation procedures were performed on patients under 12 years. The mean time a patient was submitted to surgery was approximately every 14.4 months.

Table 1 presents the epidemiological data. There were 11 (40.74%) male and 16 (59.26%) female patients. The median age at the initial procedure was 43 months.

The main diagnoses that motivated the initial transtibial amputation procedure were congenital (14; 51.85%), trauma (6; 22.22%), infectious (6; 22.22%), and rheumatological (1; 3.71%).

Eighteen patients developed symptomatic spurs that required revision, corresponding to 66.66% of the operated cases. The mean time to identify the spur in those submitted to new procedures was 53 months after the first procedure, while the time until the new approach was around 62 months. When comparing each group, there was no statistical difference between them ($p = 0.351$).

The survival rates leading to surgery were compared across different diagnoses. Patients requiring surgery due to congenital infections showed a mean survival of 44.2 months (SD 15.52). In contrast, patients with traumatic amputations demonstrated the lowest survival, with a mean of 25.1 months (SD 5.84). The overall survival rate for amputation was 43.2 months (SD 14.24) (Figure 3). The age difference at primary amputation between those who presented spurs and those who did not was one year. The younger individuals were more likely to show this complication. However, this difference did not present statistical significance ($p = 0.64$).

Table 1. Epidemiological data

Sex	Age of the amputation (months)	Diagnosis	Bone overgrowth	Time between amputation and revision (months)
F	24.1	Trauma	Yes	8.3
F	116.4	Infection	Yes	9.7
F	95.5	Congenital	Yes	16.3
F	145.4	Congenital	Yes	16.5
M	106	Trauma	Yes	22.7
M	24.3	Infection	Yes	24.4
F	15.2	Trauma	Yes	27.5
M	18.9	Congenital	Yes	29.7
F	124.4	Congenital	Yes	31.7
F	60.9	Trauma	Yes	41
M	60.1	Congenital	Yes	43.2
M	22.3	Infection	Yes	44.2
M	17.9	Congenital	Yes	71.2
F	118.5	Congenital	Yes	78.6
F	42.7	Infection	Yes	84.1
F	20	Congenital	Yes	99.6
M	43.2	Infection	Yes	100.8
F	6.1	Congenital	Yes	152.6
M	5	Reumatologic	No	
F	8	Congenital	No	
M	26.7	Congenital	No	
F	32.2	Congenital	No	
F	84.5	Trauma	No	
M	92.2	Congenital	No	
F	107.6	Infection	No	
F	110.6	Congenital	No	
M	147.3	Trauma	No	
Mean (SD)	62.1 (47)			50.1 (39)

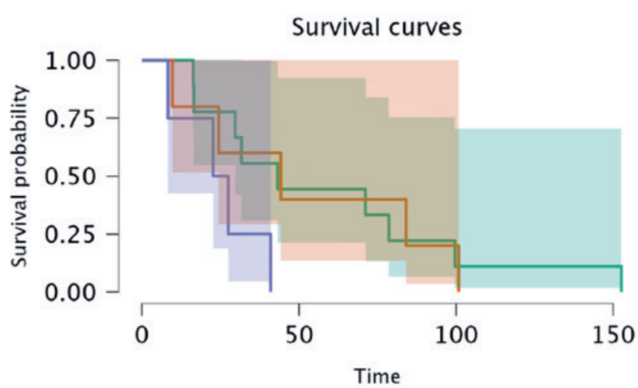

Figure 3. Graph showing the survival time of the procedure between each diagnosis. Purple line trauma, orange line infection, and green line congenital.

Discussion

Twenty-seven patients were included for descriptive analysis. All of them were children or adolescents under 12 years. In our sample, it was observed a female predominance, representing 59.26% of amputated patients. This differs from the study by Horsch et al.[6], who presented a case series of 22 juvenile amputations with male predominance. Most of the strong evidence available provides data related to adult patients, and in this case, male predominance in amputation is a pattern observed in all age groups[9,10]. However, this still justifies further investigation to determine the reasons behind this predominance since the sample size in both studies in children is too small to define a determining pattern.

The indication for lower limb amputation in the pediatric population is quite variable. While in adults, 80% to 90% of amputations occur due to vascular abnormalities, in Brazil, pediatric amputations are performed mainly to treat tumors, trauma, infections, and congenital alterations[1,2,5,6,11]. In our sample, the highest prevalence was among congenital amputations (51.85%), followed by trauma and infection (22.22% each). The absence of patients with tumors is related to a specific group performing oncological surgeries in our institute, and new treatments with limb preservation methods are highly effective[12].

Bone overgrowth is the most frequent complication observed in the amputation stumps of our patients, occurring in 18 of the 27 amputated patients (66.66%). Although preserving the proximal growth plate, transtibial amputation often leads to bone overgrowth at the distal end, which may grow until growth becomes stationary in amputees[12]. Consistent with our findings, the literature shows that bone overgrowth is the most prevalent complication following lower limb amputation in this population, occurring in up to 50% of cases, with younger individuals being more likely to experience this issue[13-15]. This may explain why this complication is so frequent in our population, secondary to the young age of the individuals included.

All amputees in our study who presented with complaints related to bone spurs underwent revision surgery (18 of 18 patients). Unlike in adults, where soft tissue pathology is reported to be the most common indication for revision surgery, followed by infections[16], in our pediatric sample, all revisions were related to bone overgrowth pathology. Although different from what the literature described in the adult population, our study confirms what Horsch et al.[6] described, presenting retrospective cases in which nine patients underwent bone revision. In contrast, only one case underwent soft tissue revision surgery.

Despite the high revision rate due to bone growth, there is no alternative to amputation in terms of providing a good long-term functional result. Although some studies suggest that bone bridges may be more durable[17,18], they have methodological flaws that make comparative analysis difficult. Other studies do not confirm this, and in our sample, there were also amputations in which it was performed bone bridges evolved with the need for revision due to spur formation since the presence of the elastic periosteum in itself constitutes a risk factor for stimulating local bone growth when moving away from the stump[7].

Another method to reduce overgrowth is using caps, which can be biological or synthetical[19-21]. The synthetic materials described for use in this technique include Teflon and synthetic polytetrafluoroethylene, while the biological materials reported in the literature comprise vascularized bone segments, the proximal or distal cartilaginous portion of the fibula, and iliac grafts[19-21]. Studies indicate that both techniques reduce the likelihood of overgrowth but introduce new risks, such as infection and foreign body reactions in the affected region.

Transtibial amputations in children are rare; however, when they occur, it is common for a sharp spur to form at the bone end that can gradually penetrate the overlying soft tissues. This, in turn, results in a significant impact on the lives of affected patients in terms of pain and activities of daily living, which can also negatively impact their mental health. In these circumstances, revision surgery is often essential to improve function, and it is important that patients—and especially their family members—understand how frequently such revision procedures may be necessary (Figure 4).

Our study has several limitations, most notably its limited sample size, retrospective design, and the evaluation of multiple amputation techniques within the same sample. Despite these limitations, it presents a large series of transtibial amputations, demonstrating that the emergence of spurs remains a significant issue and that surgeons and family members should remain vigilant.

Conclusion

Bone spurs are a common complication of transtibial amputation in children, regardless of the technique used for the procedure. Understanding the existence of this condition allows physicians to educate families and children about this possibility and prepare them for possible new procedures.

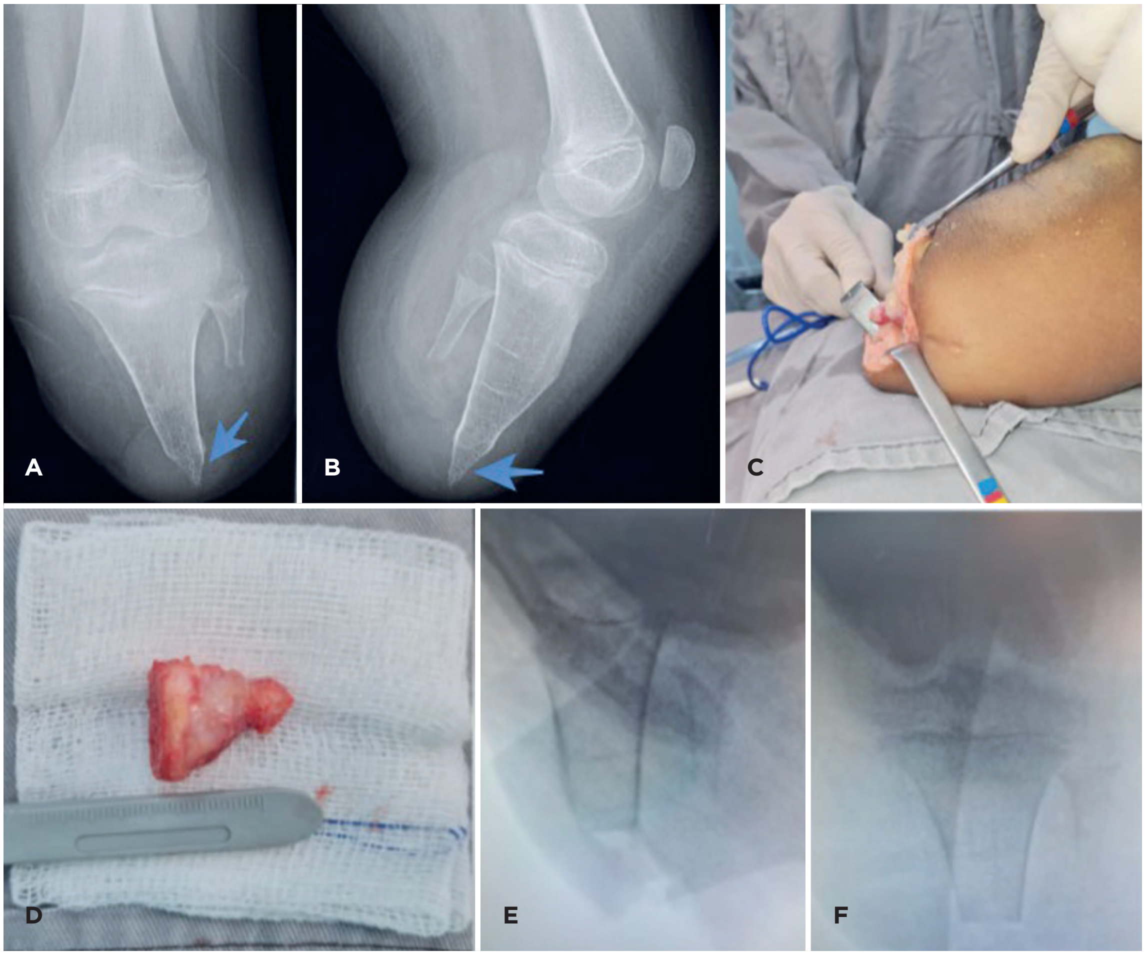

Figure 4. (A and B) Anteroposterior and lateral radiograph images showing a distal spur formation on the tibia (blue arrow) (C and D) Surgical procedure involving exposure and resection of the spur, respectively (E and F) Intraoperative fluoroscopy images demonstrating the resection of the bone spur.

Authors' contributions: Each author contributed individually and significantly to the development of this article: SM *(https://orcid.org/0000-0002-5025-4338) Conceived or planned the activities that led to the paper, interpreted the results achieved, or both; ERC *(https://orcid.org/0000-0003-0348-382ˈ) Conceived or planned the activities that led to the paper, interpreted the results achieved, or both; DLR *(https://orcid.org/0000-0003-0183-8641) Written the paper or reviewed the successive versions and participated in the reviewing process, approved the final version; RBS *(https://orcid.org/0000-0003-1085-0917) Written the paper or reviewed the successive versions and participated in the reviewing process, approved the final version; GF *(https://orcid.org/0009-0002-3377-8006) Written the paper or reviewed the successive versions and participated in the reviewing process, approved the final version; TDF *(https://orcid.org/0000-0002-9687-7143) Written the paper or reviewed the successive versions and participated in the reviewing process, approved the final version; ALGS *(https://orcid.org/0000-0002-6672-1869) Written the paper or reviewed the successive versions and participated in the reviewing process, approved the final version. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Original Article

"Saving the crippled foot" – a study on diabetic foot ulcers and its salvage using flap surgeries

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Abstract

Objective: Emphasize the importance of a comprehensive and aggressive management with surgical debridement and flap-based reconstruction of defects in patients with diabetic foot ulcers (Ganga Class 3), and in turn, focusing on limb salvage.

Methods: A retrospective cohort analysis was conducted on 40 patients with Ganga Class 3 diabetic foot submitted to flap surgeries between 2019 and 2022. These surgeries included both free and local flaps, and patients were followed postoperatively to monitor complications such as flap necrosis, infection, and the need for amputation. A pedobarogram was performed after wound healing to assess the risk of ulcer recurrence.

Results: The mean age of the study population was 58.5 years, with 75% being male. Most ulcers (60%) were located in the hindfoot, with large hindfoot ulcers often requiring anterolateral thigh-free flaps, which showed excellent long-term outcomes. While effective for smaller defects, local flaps demonstrated higher complication rates, particularly flap necrosis in reverse sural artery flaps. Despite these complications, flap surgeries were largely successful, with only one patient requiring amputation, achieving significant success in limb salvage.

Conclusion: Given that India is considered the diabetic capital of the world, with 85% of amputations preceded by foot ulcers, this study highlights the potential for surgical management of diabetic foot ulcers, regardless of size or location, emphasizing the importance of limb salvage in improving patient outcomes.

Level of evidence: Level IV.

Keywords: Diabetic foot; Amputation, surgical; Limb salvage; Surgical flaps.

Introduction

The prevalence of diabetes mellitus in India stands at 8.8%[(1)]. The diabetic foot has become one of the most common and serious complications of diabetes mellitus and is a frequent cause of hospitalization and disability. Diabetic foot ulcers were found in 4.54% of patients newly diagnosed with type 2 diabetes mellitus in India; of these, 46.1% had neuropathic, 19.7% ischemic, and 34.2% had neuro-ischemic foot ulcers[(2)].

Advancements in diagnosing and treating diabetes and its complications, including retinopathy, nephropathy, neuropathy, and foot ulcers, have significantly extended patient's lifespans and improved their quality of life. One of the most severe complications, however, is diabetic gangrene. While the causes of diabetic wounds typically involve both angiopathy and neuropathy, often due to reduced sensation and, at times, impaired blood flow, the underlying mechanisms of neuropathy, ischemia, and microangiopathy play varying roles in hindering healing. These factors contribute to complex tissue damage and make wounds highly vulnerable to persistent, hard-to-treat infections[(3-5)].

Patients with diabetes who develop foot ulcers have increased mortality[(6)] compared with those who have intact feet (15% lower survival at 3 years), reduced quality of life, and are more likely to require amputation[(7,8)]. Several studies have shown that an amputation affects the quality of life only

Study performed at the Father Muller Medical College, Mangalore, Karnataka, India.

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a minority of patients regain independent walking capacity[7], and the direct and indirect costs are much higher than limb salvage procedures[8,9].

First, all patients underwent a radical debridement of the infected/necrotic area, followed by vacuum-assisted closure (VAC) application for 3-5 days. After this period, the wound was reassessed, and an appropriate flap was planned. The patients then underwent a secondary debridement, and an appropriate flap surgery was performed. Larger size wounds and wounds enveloping the joints were planned for microvascular free tissue transfer, while local skin or muscle-based flaps were planned for coverage of smaller-sized defects.

This study aims to emphasize the importance of comprehensive and aggressive management with surgical debridement and flap-based reconstruction of defects in patients with diabetic foot ulcers (Ganga Class 3) and, in turn, focusing on limb salvage. By prioritizing limb preservation, the study seeks to explore and validate various surgical techniques that minimize the need for amputation, regardless of the severity of the condition, thereby improving patient outcomes and quality of life. We hypothesize that a thorough debridement of infected and devitalized tissue, irrespective of the size and site of the ulcer, along with an adequate vascularized flap cover, can help not only arrest and reverse the progression of disease but also save the foot from the need for amputation and improve the quality of life in such patients.

Materials and methods

Study design

In a retrospective cohort, 40 patients with diabetic feet were classified based on Ganga classification for diabetic feet – pre-ulcerative changes (Ganga Class 1), chronic uncomplicated non-healing ulcer (Ganga Class 2), complicated ulcer and extensive skin and soft tissue loss (Ganga Class 3) and neglected ulcers which have progressed to limb- or life-threatening situations necessitating urgent amputation (Ganga Class 4). Patients with (Ganga Class 3) who were operated on between 2019 and 2022 were selected for the outcome of subsequent flap surgeries. Flaps of two categories were included – free and local flaps. The free flaps comprised anterolateral thigh free flaps and radial forearm free flaps, and the local flaps comprised transposition flaps, reverse sural artery flaps, and flexor digitorum brevis flaps. After obtaining necessary institutional ethical clearance, patients satisfying the inclusion criteria of (1) 18 years and above and (2) patients with Ganga Class 3 diabetic feet were included, and patients were excluded if they (1) had a concomitant peripheral vascular disease, and (2) patients lost to follow-up. Patients were then evaluated on routine follow-ups for complications such as (1) flap necrosis (2) infections, and (3) need for amputation. The inclusion-exclusion criteria were identified based on previous medical records. A pedobarogram was performed on subsequent follow-ups at six and 12 months for all patients after complete wound healing to assess the potential risk of developing another ulcer. The study protocol was approved by the institutional review board. After explaining the study, all patients signed the informed consent form.

Surgical techniques

All patients were evaluated for size and site of ulcers, and a vascular evaluation was performed using a computed tomography angiogram. After confirming adequate vascularity, patients first underwent a preliminary wound debridement, followed by VAC application for 3-5 days. After this period, the wound was reassessed, and an appropriate flap was planned. Smaller defects with an adequate soft-tissue bed required only a local flap rotated around an existing vascular pedicle, whereas larger defects or defects over bony prominences and joints required free flaps with vascular anastomosis. Amongst the local flaps, based on the location of the ulcer over the foot, the nearest local flap that could be elevated to cover the defect while maintaining the native vascular supply was chosen. The patients then underwent a secondary debridement and an appropriate flap surgery was performed. Our study involved free microvascular anterolateral thigh flap transfer, harvested from the contralateral thigh outlined along the axis of the anterior superior iliac spine and superolateral corner of the patella, with the identification of vascular pedicle consisting of the descending branch of the lateral circumflex femoral artery and its accompanying veins, present along the axis of vastus lateralis and rectus femoris. Radial forearm free flaps with a pedicle consisting of the radial artery with its perforators to the overlying skin and its accompanying vena commitans and cephalic vein for venous drainage was used, and the donor sites in these microvascular free flap cases were partially closed while the remaining area, grafted with a split-thickness skin graft. Patients underwent local transposition or rotation of skin flaps, which were rotated around the native pedicle, supplying the flap locally. Reverse sural artery flap (a distally based fasciocutaneous flap consisting of skin, superficial and deep fascia, sural nerve, short saphenous vein, and superficial dual artery) and peroneus brevis muscle flap were used to cover critical raw areas.

Postoperative evaluation

Patients received routine postoperative care, limbs were immobilized using off-loaded plaster-of-Paris slabs, and anti-coagulant therapy was initiated for the patients who underwent free flaps. Regular dressings were performed, and flaps were monitored for any signs of necrosis or repeat infection. Patients were discharged with instructions to continue wound dressings at home and were scheduled for regular follow-up on an outpatient basis. After wound healing, a pedobarogram was conducted for all patients, and appropriate off-loading footwear was prescribed. Patients who developed complications such as flap necrosis or infection underwent further debridement with a repeat flap cover using the same flap selection protocol used in the index surgery. If vascularity to the distal extremity was found to be compromised with no other alternative, such patients underwent amputation.

Statistical analysis

Data were collected and subjected to both descriptive and inferential statistical analysis. Continuous variables such as patient age, ulcer size, and HbA1c levels were expressed as mean ± standard deviation (SD). Logistic regression was used to assess the association between continuous variables and the risk of developing postoperative complications. A logistic regression model was created for each complication, using the continuous variables as predictors. The significance of each predictor was evaluated using p-values, and a threshold of 0.05 was set for statistical significance. Fisher’s exact test was applied to assess the relationship between different flap types and postoperative complications due to its suitability for small sample sizes and categorical data. Contingency tables were constructed for each flap type and complication pair, and Fisher’s exact test was used to compute p-values. A p-value of less than 0.05 was considered statistically significant. Data analysis was performed using SPSS version 29.

Results

The mean age of our patient population was 58.5 years and was predominantly male (75%). The mean HbA1c was 8.3, the mean ulcer duration was two months, and the mean size was 49.67 cm^2. Out of 40 patients with Ganga Class 3 diabetic feet, 19 underwent local flaps – transposition flap (11), flexor digitorum brevis flap (5), and reverse sural artery flap (3), 15 underwent anterolateral free flaps, and six underwent radial forearm free flaps. Most ulcers were in the hindfoot (24) followed by the forefoot (10) and midfoot (6) respectively (Figure 1). Nineteen ulcers were found to be over a weight-bearing area, while 21 were over a non-weight-bearing area. Hindfoot ulcers were primarily covered using anterolateral free flaps (41%), midfoot ulcers using radial forearm free flaps, and forefoot ulcers using transposition flaps (Figure 2). The mean area of ulcers requiring anterolateral free flaps was 186 cms^2, ranging from 150-300 cms^2. Radial forearm free flaps, which were primarily used to cover defects in the midfoot and forefoot, were used for defects from 40 cms^2 up to 90 cms^2, with a mean size of 58.3 cms^2. The local flaps, namely transpositional flaps, reverse sural artery flaps, and flexor digitorum brevis flap, were used for smaller defects with a mean size of 27.6 cms^2, 28 cms^2, and 36.6 cms^2 respectively (Figure 3). Complications such as flap necrosis were seen in 3(7.5%) patients, with two in reverse sural artery flaps and one in a flexor digitorum brevis flap; repeat infection and the need for amputation were seen in one patient (2.5%) (Figure 4).

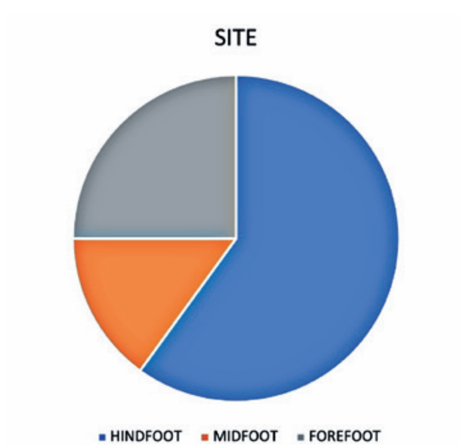

Figure 1. Site of involvement in diabetic feet.

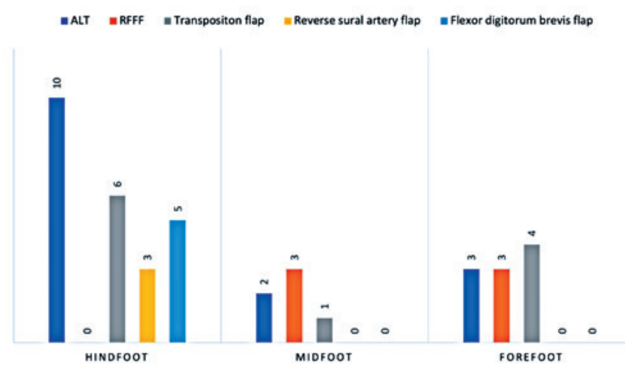

Figure 2. Types of flaps used over different parts of the foot.

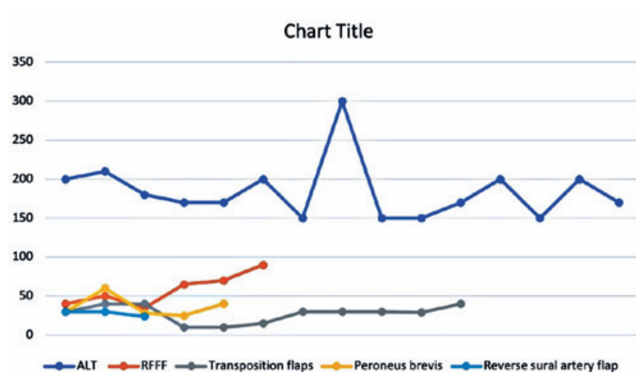

Figure 3. Surface area (cms^2) of ulcers covered using different flaps.

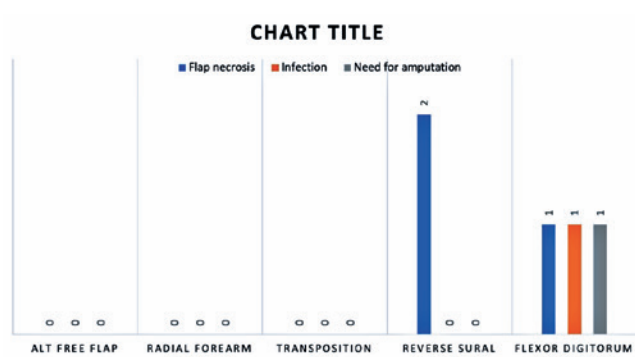

Figure 4. Complications associated with various flap surgeries.

A logistic regression analysis for factors affecting flap complications showed no statistical significance as a causal factor (Table 1).

Discussion

Diabetes affects an estimated 463 million adults worldwide, with India being home to over 70 million diabetics, earning the title of the diabetic capital of the world[2]. Diabetic foot complications, especially foot ulcers, are a significant burden on the healthcare system, being the primary cause of hospitalization in about 30% of diabetic patients[4]. Treating diabetic foot ulcers accounts for 20% of healthcare costs for diabetics[4]. Foot ulcers precede 85% of amputations, with 75% occurring on neuropathic feet with secondary infections, which are potentially preventable[5]. In India alone, around 100,000 legs are amputated annually due to diabetes, with the numbers rising[4].

Our study evaluated the outcomes of flap surgeries in patients with Ganga Class 3 diabetic feet. The ulcers were most commonly located in the hindfoot, followed by the forefoot and midfoot, with a majority in non-weight-bearing areas. Complications were minimal, with flap necrosis occurring in only three patients and one infection requiring amputation.

Three key factors contribute to diabetic foot ulcers: neuropathy, limited joint mobility, and ischemia. High blood sugar levels disrupt the myoinositol sorbitol pathways in neurons, causing nerve dysfunction[10]. Neuropathy affects motor, sensory, and autonomic components, with motor neuropathy leading to deformities due to intrinsic muscle atrophy. These deformities result in focal areas of high pressure on the plantar aspect of the foot. Sensory neuropathy diminishes protective mechanisms, while autonomic neuropathy reduces skin moisturization, leading to cracks and delayed wound healing[11]. Chronic uncontrolled diabetes also leads to the deposition of advanced glycation end products (AGE) in soft tissues, altering collagen and elastin properties, limiting joint mobility, and causing high plantar pressures[6]. Callosities increase pressure, leading to sub-callus ulcers, which can develop into deep tissue abscesses or osteomyelitis, spreading infection along soft tissue and tendon planes[11]. Additionally, vascular complications in diabetic patients can result in gangrenous ulcers due to thickened capillary walls and endothelial cell proliferation. Surgical bypass may sometimes be required to revascularize affected areas[7].

Table 1. Logistic regression analysis relationship between various continuous predictors (age, duration of diabetes, HbA1c, and ulcer area) and the development of postoperative complications (flap necrosis, infection, sepsis, and death).

	Flap necrosis	Infection	Sepsis	Death
Age	0.228287393	0.228287	0.228287	0.228287
Duration	0.774801616	0.774802	0.774802	0.774802
HbA1c	0.788224193	0.788224	0.788224	0.788224
Area	0.977747577	0.977748	0.977748	0.977748

Although ulcers are generally known to be more prevalent in weight-bearing areas, most of the ulcers in our study were found to be in non-weight-bearing areas. This highlights the importance of recognizing diabetic ulcers as not just a mere chronic pressure-sore but a complex issue with various confounding factors like loading of bony prominences from altered biomechanics in diabetic neuropathy, poor wound healing of small but otherwise unrecognized injuries of the foot due to uncontrolled sugars, and skin breakdown from poor vascularity resulting from diabetic microangiopathy. Thus, treating these ulcers requires offloading footwear, strict diabetic control, revascularization of the local soft tissue by debridement and flaps, and in some cases, even reconstruction of the bony architecture of the foot.

Diabetic wounds, even small ones, often mask the extent of the underlying infection. Superficial ulcers may be accompanied by tracking infections along soft tissue planes, leading to chronic osteomyelitis. Wound care in such cases must focus on removing all infected and necrotic tissue. In this study, patients underwent primary debridement with VAC therapy for a mean of 4-5 days, followed by secondary debridement before flap cover surgery. This approach improved wound prognosis and increased the success of reconstructive procedures. The suppressed immune system in people with diabetes further accelerates wound infections, making patients susceptible to resistant infections, particularly in bones[8,12]. Treating osteomyelitis requires aggressive management, including complete removal of necrotic tissue, decompression of infected compartments, filling dead spaces with vascularized tissues, and appropriate antibiotic therapy.

In the past, primary major amputations were common for large soft tissue deficits in diabetic feet, particularly on weight-bearing surfaces. However, only a small percentage of amputees regained full mobility, and limb loss had significant physical, mental, and financial consequences. A review of 45 studies including 419 patients, 149 patients who underwent amputation between 1948 and 2010 reported 30-day mortality rates of 16.45% and one-year mortality rates of 33.49%, emphasizing the need for combined interventions over early amputation in patients with viable outflow vessels[13,14].

Local random flaps have been used in reconstructive surgery for centuries, with the first use in diabetic foot wounds documented by Colen et al. in 1988[15]. These flaps are ideal for certain wounds that cannot be closed primarily or treated with skin grafts. Local random flaps, including advancement, rotational, and transpositional flaps, replace soft tissue defects with adjacent tissues, preserving the site's structure and function[16]. Free-tissue transfer offers effective solutions for more complex defects, especially in limb salvage. Studies have shown that free flaps can promote revascularization in ischemic limbs by forming vascular connections between the flap and surrounding tissue. This technique has proven successful in treating large diabetic ulcers that would otherwise lead to amputation[17-22]. The best flaps for diabetic foot reconstruction provide well-vascularized tissue to combat infection, structural support for durability, and resistance to mechanical stress[23]. Muscle flaps are preferred over fasciocutaneous flaps for their adaptability to the foot's irregular surfaces and superior infection control, especially in cases of osteomyelitis. Muscle flaps provide cushioning to prevent further tissue breakdown, but the lack of sensation can increase the risk of recurrent complications[24-26]. Despite this, muscle flaps are favored for managing complex defects, improving wound healing, and preserving the limb.

Our study examined the outcomes of local flaps in treating diabetic ulcers in various parts of the foot. Local transposition flaps, flexor digitorum brevis flaps, and reverse sural artery flaps were used, mainly for hindfoot ulcers, with some transposition flaps for forefoot and midfoot ulcers (Figures 5-7). While effective for smaller defects, local flaps showed higher rates of necrosis and repeat infections, particularly with reverse sural artery flaps. For larger ulcers, we employed anterolateral thigh free flaps (Figure 8-11) and radial artery forearm free flaps (Figure 12), both commonly used in our institution. Anterolateral flaps were used for hindfoot and large midfoot and forefoot defects, showing excellent results with no long-term complications. Some patients later required secondary procedures to debulk the flaps. Radial forearm flaps were used for medium-sized wounds in the midfoot, offering reliable coverage due to their larger, more

Figure 5. (A) Forefoot ulcer (B) Post preliminary debridement (C) Medial plantar artery-based local transposition flap elevation (D) Flap onset (E) One-month follow-up (F) One-year follow-up showing complete wound healing.

Figure 6. Postoperative follow-up cases of healed reverse sural artery flap.

Figure 7. (A) Forefoot ulcer (B) Post-wound debridement with flexor digitorum brevis muscle cover (C) Skin grafting over muscle flap (D) Two-month follow-up showing complete healing of plantar ulcer.

Figure 8. (A) Hindfoot ulcer (B) Post preliminary debridement (C) Anterolateral thigh free flap onset (D, E, and F) One-year follow-up, with complete recovery and independent ambulation.

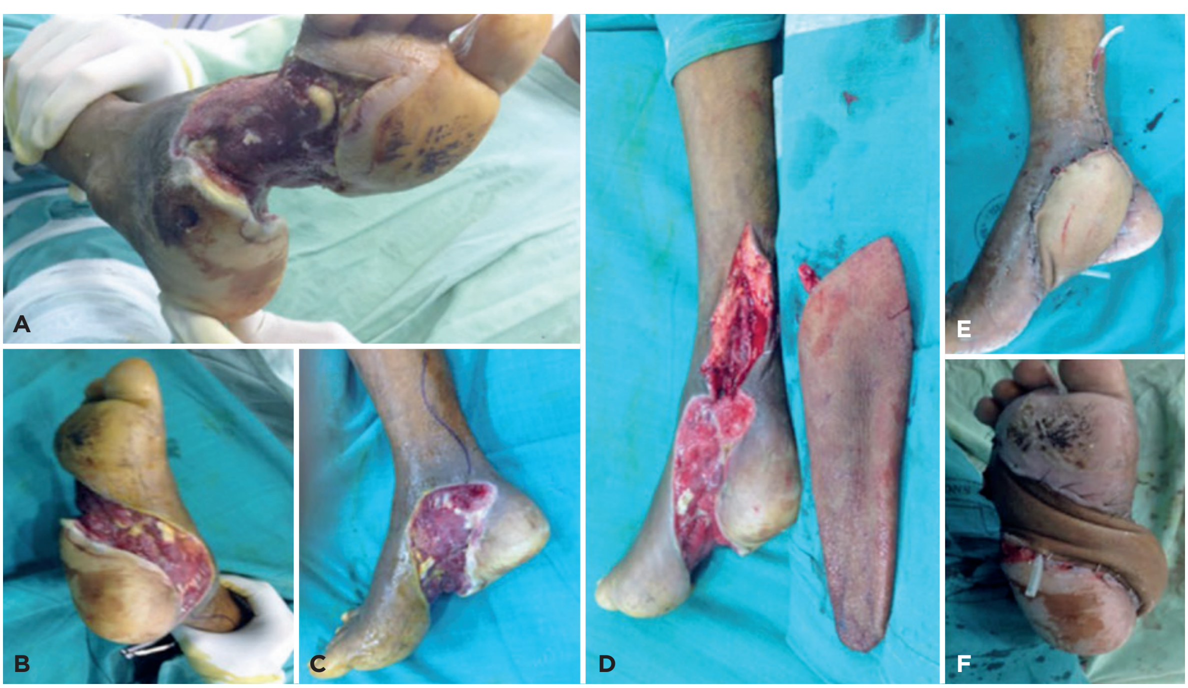

Figure 9. (A, B, and C) Midfoot ulcer (D) Post preliminary debridement with harvested anterolateral free flap (E, F) Anterolateral thigh free flap onset.

Figure 10. (A, B) Forefoot ulcer (C) Post preliminary debridement (D) Post-secondary debridement (E, F) Anterolateral thigh free flap inset.

Figure 11. (A) Massive anterolateral flap (B) Post-debridement (C) Flap inset (D) One-month follow-up (E) One-year follow-up with complete wound healing and ambulation using modified footwear.

Figure 12. (A) Forefoot ulcer (B) Two-week follow-up post-radial artery forearm free flap onset.

reliable pedicles, which minimize vessel mismatch and allow for easy microsurgical anastomoses. The radial forearm flap also provides thin, pliable tissue that adapts well to the foot contour, allowing patients to wear normal footwear without needing secondary surgeries. All patients with radial forearm flaps completely recovered with good flap uptake and no complications[27].

The existing literature showed results comparable to our study on diabetic foot ulcers and flap surgeries. An algorithm-based approach described by Armstrong et al.[28] incorporated debridement, infection control, vascular assessment, and reconstruction, achieving a 96% limb salvage rate, emphasizing a comprehensive management protocol with multidisciplinary care being integral to improving patient outcomes. While we excluded cases with peripheral vascular disease due to its confounding effect on flap survival, Randon et al.[29] examined 55 patients undergoing combined arterial reconstruction and free flap transfers with a limb salvage rate of 80%, lower than our current study's 97.5%. Similarly, a prospective study by Azhar et al.[30] highlighted the impact of peripheral arterial disease (PAD) on limb salvage, with amputation rates reaching 53.8% in PAD-associated diabetic ulcers and highlighting the possible context of PAD that may account for this discrepancy.

Although many flaps are available for lower limb defects, several factors influence the outcome, including lower limb vascularity, bony deformities, and diabetic control. Our study demonstrated the potential to salvage diabetic feet using appropriate soft tissue procedures. Successful ambulation was defined as the ability to walk independently or with assistance. All our patients achieved independent ambulation within 3-6 months postoperatively. While our study showed successful flap outcomes with minimal complications, wound management does not end with surgery. We successfully converted Ganga Class 3 diabetic feet to class 1, as evidenced by postoperative pedobarograms. Patients were prescribed off-loading modified footwear and taught proper foot care to prevent ulcer recurrence.

Limitations of our study included a small patient population and a selection bias due to the retrospective study design. Although we assessed flap outcome and disease progression, we did not include quality of life measures on long-term follow-up, which can be a potential study area in the future. Strengths of the study include cases involving a wide spectrum of disease severity, from small ulcers to large soft tissue defects, and diverse surgical approaches that can be performed for each type of ulcer based on its location and size. Additionally, surgeries performed by a single senior specialist remove any confounding factors that may have caused the difference in surgical quality. Lastly, the long-term follow-up with a subsequent pedobarogram completes the follow-through of the surgical procedure.

Conclusion

Our study highlights the spectrum of the diabetic foot that can be effectively managed surgically, regardless of ulcer location or size. Diabetic feet can—and must—be salvaged. However, surgery is one of many challenges in the broader fight against this condition. A holistic approach is essential, encompassing strict diabetic control and adherence to postoperative modified footwear to ensure optimal long-term outcomes.

Authors' contributions: Each author contributed individually and significantly to the development of this article: LL *(https://orcid.org/0009-0005-2213-8988) Conceived and planned the activities that led to the study, interpreted the results of the study, performed the surgeries, data collection, statistical analysis, survey of the medical records, approved the final version and wrote the article; AXJ *(https://orcid.org/0000-0002-3604-5863) Conceived and planned the activities that led to the study, interpreted the results of the study, data collection, statistical analysis, survey of the medical records, approved the final version and wrote the article; MMA *(https://orcid.org/0009-0003-6554-6370) Conceived and planned the activities that led to the study, interpreted the results of the study, performed the surgeries, data collection, statistical analysis, survey of the medical records, approved the final version and wrote the article; TM *(https://orcid.org/0009-0001-4417-4454) Data collection, statistical analysis, survey of the medical records; VA *(https://orcid.org/0009-0008-1839-6118) Conceived and planned the activities that led to the study, interpreted the results of the study, approved the final version and wrote the article. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Original Article

Development of an application for identification and guidance on orthopedic foot diseases

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Abstract

Objective: Develop software to identify the main orthopedic diseases affecting the feet and guide patients by assessing pain intensity and the application's (APP) diagnostic accuracy.

Methods: The software was developed by the Creation Department of Unichristus University. Over two months, 22 patients seeking orthopedics assistance for foot pain were recruited. During the scheduling, they were invited to participate in the study and received a link to download the APP. After signing the informed consent form and using the APP, the patient's pain intensity and APP-suggested results were collected and compared to the medical diagnosis recorded in electronic health records after consultation.

Results: The APP was developed with information on the main orthopedic foot diseases. It showed high accuracy for hallux valgus (100%), plantar fasciitis (75%), metatarsalgia (66.67%), and calcaneal tendinopathy (66.70%). However, the overall concordance with medical diagnoses was 40.90%. Pain intensity primarily ranged between 6 and 8 (68.20%).

Conclusion: The APP yielded positive results in identifying specific orthopedic foot diseases with relevant pain intensities but did not achieve high overall concordance. Further studies are needed to create more accurate diagnostic flowcharts.

Level of Evidence; Diagnostic studies - investigating a diagnostic test.

Keywords: Mobile applications; Validation study; Health education.

Introduction

Foot and ankle-related diseases have a high incidence and are widely prevalent across the population, affecting individuals of all sexes, age groups, races, and social classes[1]. The prevalence of each pathology also varies according to these factors. For instance, hallux valgus is highly prevalent among older people and contributes to postural instability, other foot deformities, and even loss of independence in this population[2]. These conditions can lead to work-related impairments, hinder recreational and professional sports activities, cause emotional issues (such as anxiety and depression), and result in an overall reduction in individuals' quality of life[3,4].

Despite the significant impact these pathologies can have on daily life, attention to the feet and ankles is often neglected. Symptoms, including pain, are frequently ignored, and the conditions are only identified after thorough consultations or objective evaluation tools, such as the Foot Function Index (FFI)[5,6]. These diseases are treated by various healthcare professionals, including General Practitioners, General Orthopedic Surgeons, Foot and Ankle Specialists, Physical Therapists, and Podiatrists[7-9]. Treatments range from lifestyle changes, adjustments to physical activities, and shoe modifications to using pre-molded or custom orthotic insoles and surgical procedures[10]. However, these approaches are not uniformly applied, particularly in the

Study performed at the Dr. Vagner M. Paiva Clinic, Fortaleza, CE, Brazil.

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early stages, where simple measures such as weight loss, temporary modifications to physical activity, stretching, or heel lifts or insoles to correct foot alignment can significantly benefit patients[11,12].

In specialized foot and ankle orthopedic practice, it is observed that these diseases often follow a well-defined topographic pattern. As defined in the medical semiotic and semio-technical concept of "anatomical diagnosis," which relates anatomical structures to signs and symptoms, the area where the patient experiences the most intense pain is usually associated with one or two specific conditions, which can often be easily differentiated using a simple flowchart. This is because the foot's complex bony structure is designed to absorb load and support the body, while its thin subcutaneous tissue layer makes critical structures such as tendons, fasciae, retinacula, joints, and nerves easily palpable and susceptible to acute or chronic injuries, even without significant trauma. As a result, foot and ankle orthopedic specialists can often identify certain conditions without imaging studies. Similarly, patients who can pinpoint the location of their pain and have basic knowledge about foot diseases affecting that specific area could also gain an understanding of the condition affecting them[13-16].

This concept has already been implemented for pregnant women with access to approximately mobile applications providing information on risk factors for preeclampsia, enabling early medical intervention if needed[17-19]. With proper information, patients could adopt palliative measures to improve their quality of life while awaiting specialized orthopedic care. These measures might include weight loss, stretching the posterior chain of the lower limbs, adjusting physical activities to prioritize low-impact exercises, avoiding certain footwear types, and using comfort insoles[19-22]. Given this, the present study aims to develop a mobile application (APP) specifically designed for portable devices to guide the main diseases affecting each foot region. The APP will use a simple flowchart to help individuals identify potential conditions, access information about them, and initiate basic measures often sufficient for temporary symptom relief until specialized medical care is available[23-25].

Additionally, the APP will assess the intensity of pain reported by patients. We hypothesize that foot-related diseases cause significant pain intensity and that the APP will enable patients to identify the likely condition affecting their feet, gain basic knowledge about it and foot health, and implement initial measures to alleviate pain while waiting for a consultation with a specialist.

Methods

The APP was developed for the two main operating systems (OS): Google's Android® (Palo Alto, California) and Apple's iOS® (Cupertino, California). The application was developed at the Technological Innovation Laboratory of Unichristus University with a Certificate of Computer Program Registration (Process No.: BR512024001974-0). The features included in the APP creation are: A 3D video of a foot with red spots indicating painful areas, each numbered; Isolated photos of the foot with the painful area numbered corresponding to the 3D foot video; Selection of corresponding photos that can be chosen by touch; Upon selecting the photo with the painful area, an informative video opens, followed by written content about the possible condition affecting that region, with basic guidance on the pathology; A tool with touch-sensitive buttons that assist the user through shortcuts for making calls to schedule medical and physical therapy appointments, foot posture tests, and contacting insole suppliers. A validation study was conducted with a sample of 22 patients with complaints of foot pain recruited from the clinic of an orthopedic physician over two months.

The study consisted of three phases. The first phase involved the development of the application; the second phase evaluated the intensity of pain and the APP's accuracy compared to the medical diagnosis. The target audience sample size was calculated using relevant indices for validation, based on the formula $n = 1.96^2.p.(1-p)/d$, and the mean convenience population, where p is the estimated proportion in the population and d is the precision with a 95% confidence level[2,24,25]. The study was conducted at the Dr. Vagner M. Paiva Clinic in Fortaleza, Ceará, Brazil. Study participants were selected through sampling calculations for validation, including 22 patients who sought orthopedic medical care with complaints of foot pain. Participants included individuals over 14 years (when foot growth cartilage is closed) who agreed to participate by signing the Free and Informed Consent Form (ICF). Exclusion criteria were patients under 14 years, those with cognitive deficits or limiting psychiatric disorders, and individuals who refused to participate. All patients received clear information about the project objectives and provided online consent via Google Forms. The patients were then guided by the evaluator to download the APP and follow the flowchart provided within the software.

Finally, the evaluator recorded the condition suggested by the APP and the pain intensity, and two questionnaires were applied: System Usability Score (SUS) and Technology Acceptance Model (TAM). During the orthopedic medical consultation, the diagnosis was documented via the electronic medical record. The following tests were applied for results analysis: Kolmogorov-Smirnov, parametric and non-parametric Mann-Whitney or Kruskal-Wallis tests, X test or Fisher's exact test. Data collection and analysis were conducted using Microsoft Office Excel and IBM SPSS Statistics. Regarding ethical aspects, patients were invited to participate in the study before the outpatient consultation, and only those who agreed and signed the ICF underwent the study procedures. It was emphasized before, during, and after the questionnaires that participants could withdraw without affecting their orthopedic consultation. Furthermore, this research and its procedures were submitted for review and approved by the Unichristus Ethics Committee under the number 5647.2622.6.0000.5049.

Results

Initially, a presentation screen was displayed, and the patient's initial registration was completed (Figure 1). After initial registration, the user clicks "Proceed" to access the other APP functions. A video with numbered red spots is shown to help the user identify the corresponding marked pain region (Figure 2). Screens with ten photos are presented, each showing a single numbered pain point corresponding to the painful area identified in the video (Figures 3 and 4).

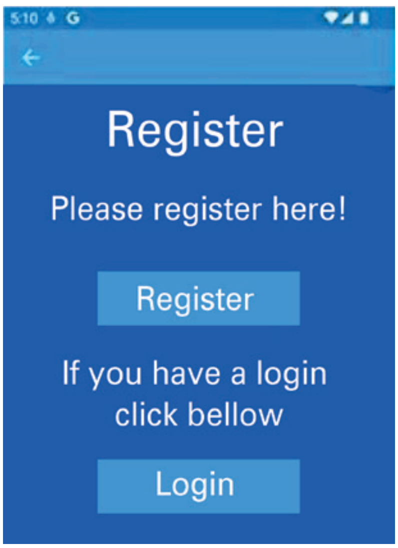

Figure 1. Registration screen.
Source: App Pés com Dor (Portuguese).

Upon clicking on an image, the user is redirected to a screen with an explanatory video and text about the main condition associated with that location (Figures 5, 6, and 7). Only one of the painful areas presents two possible conditions. A flowchart, accompanied by an explanatory video, guides the user to the screen corresponding to their probable condition (Figure 8). After completing this flowchart, the APP follows the same pattern as the other conditions.

In analyzing results for orthopedic conditions related to the feet, a table was created correlating the pain scale, the diagnosis provided by the APP, and the diagnosis obtained during the medical consultation. Regarding pain intensity, it was observed that pain levels ranged from 3 to 10, with the majority (15 cases) falling between 6 and 8 (68.2%). One patient reported pain level 3, with both the medical diagnosis and the APP-suggested condition being calcaneal tendon tendinitis (1). Another user reported pain level 4, with both the medical diagnosis and the APP-suggested condition being metatarsalgia (1). Two users reported pain level 5, with one receiving a medical diagnosis of lateral foot overload (1) and the other a diagnosis of a tumoral lesion (1). Eight users reported pain level 6, with medical diagnoses including plantar fasciitis (2), lateral foot overload (2), posterior tibial tendinitis (1), calcaneal tendon tendinitis (1), calcaneal tendon

Figure 2. Pain localization screens.
Source: App Pés com Dor (Portuguese).

Figure 3. Pain localization screens.
Source: App Pés com Dor (Portuguese).

rupture (1), and ankle instability (1). One user reported pain level 7, with medical diagnoses of metatarsalgia (1) and lateral foot overload (1). Six users reported pain level 8, with medical diagnoses of metatarsalgia (1), ankle instability (1), posterior tibial tendinitis (1), plantar fasciitis (1), hallux valgus (1), and metatarsalgia with lateral foot overload (1). One user reported pain level 9, with both the medical diagnosis and the APP-suggested condition being lateral foot overload (1). Two users reported pain level 10, with medical diagnoses of plantar fasciitis (1) and plantar clavus (1). These findings are detailed in Table 1.

The results comparing the condition suggested by the APP with the medical diagnosis revealed an overall agreement of 40.9% (Table 2). The orthopedic conditions where the APP had the highest concordance were hallux valgus (1:1, 100%), plantar fasciitis (3:4, 75%), metatarsalgia (2:3, 66.67%), and calcaneal tendon tendinitis (2:3, 66.67%).

For the remaining conditions, the correlation between the APP-suggested diagnosis and the medical diagnosis was as follows: lateral foot overload (1:3, 33.33%), fibular tendinitis (0:2, 0%), and posterior tibial tendinitis (0:1, 0%). Ten

Figure 4. Pain localization screens.
Source: App Pés com Dor (Portuguese).

questions were used for the SUS and TAM analysis, as shown in Table 3. Table 4 shows the evaluation of user acceptance, as assessed using the TAM criteria. By cross-referencing the data to relate the two aforementioned evaluations, Figure 9 shows the Spearman correlation.

Discussion

The developed application serves various purposes, from guiding the ten main orthopedic conditions related to the foot and ankle to educating users with accessible language about practical measures for maintaining foot and ankle health. These measures include weight management, appropriate footwear use, posterior chain stretching, adjusting physical activities, and using comfort insoles while waiting for specialized orthopedic care.

Additionally, the application assists users in finding services with specialized professionals, such as scheduling medical appointments (virtual or in-person), physiotherapy evaluations, gait analysis, and contacting companies that sell insoles.

Orthopedic foot and ankle conditions are a public health issue due to their high prevalence in the general population, ranging from 61%–79%. These conditions are particularly prevalent among physically active individuals. For example, plantar fasciitis affects 17.4% of runners[26], flatfoot (often associated with posterior tibial tendinitis) occurs in 5%[27], and hallux valgus affects 19% of the general population[28]. These conditions result in economic impacts due to work absences and decreased efficiency, and they impair physical activity performance, which can have repercussions on patient's physical health, such as increased obesity rates, hypertension, and diabetes. Mental health is also affected, as conditions like plantar fasciitis can lead to increased levels of anxiety, depression, and stress. Furthermore, these conditions particularly affect women by limiting their ability to wear certain types of footwear[29,30].

The study confirmed this impact, as 15 out of 22 users (68.2%) reported pain intensity levels between 6 and 8 after being told that pain level 10 would be the greatest pain a human being could endure, causing daily discomfort

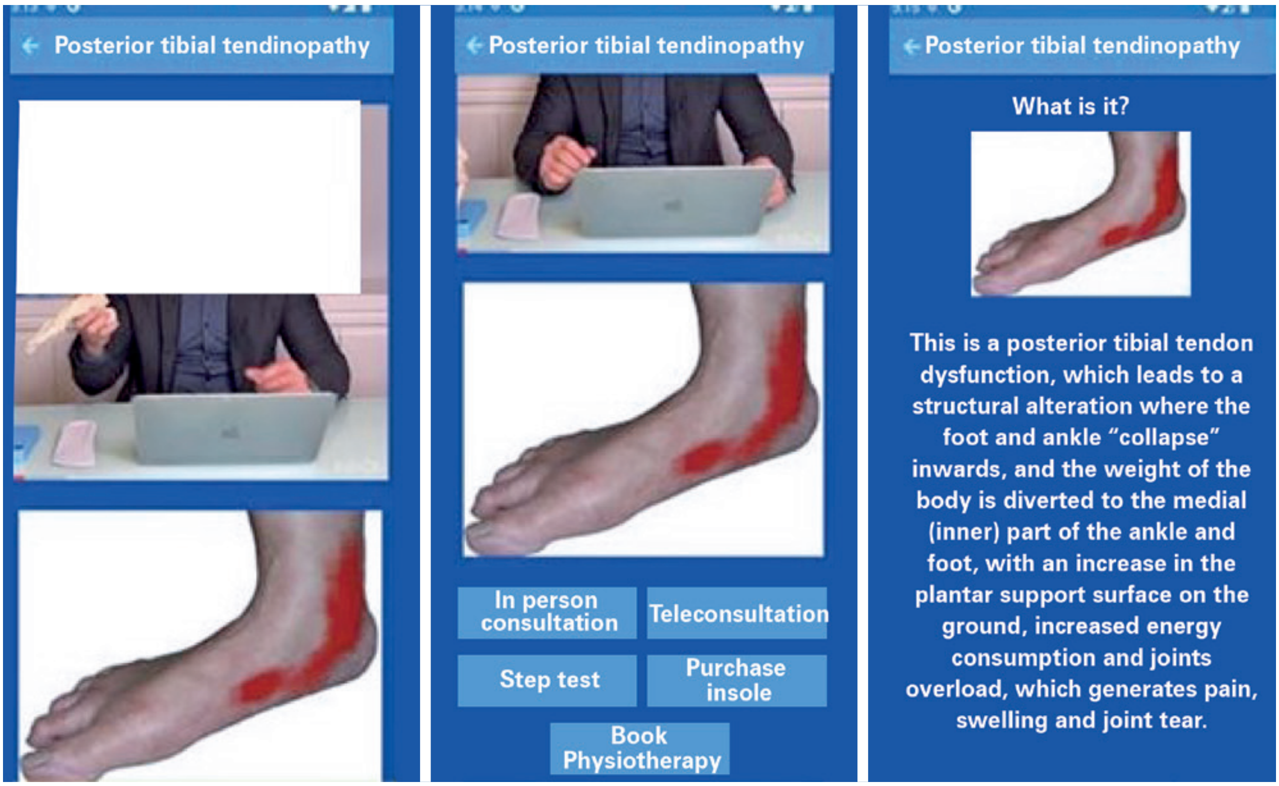

Figure 5. Informative screens about the condition and appointment shortcuts.
Source: App Pés com Dor (Portuguese).

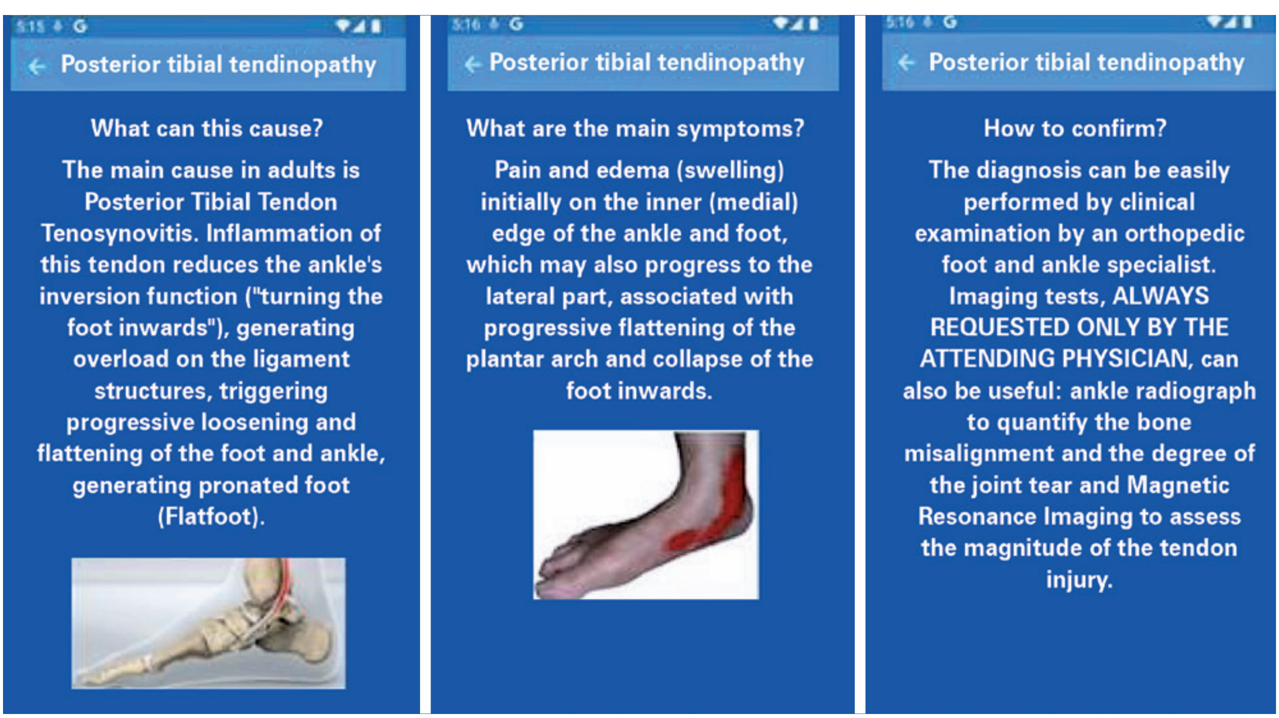

Figure 6. Informative screens about the condition.
Source: App Pés com Dor (Portuguese).

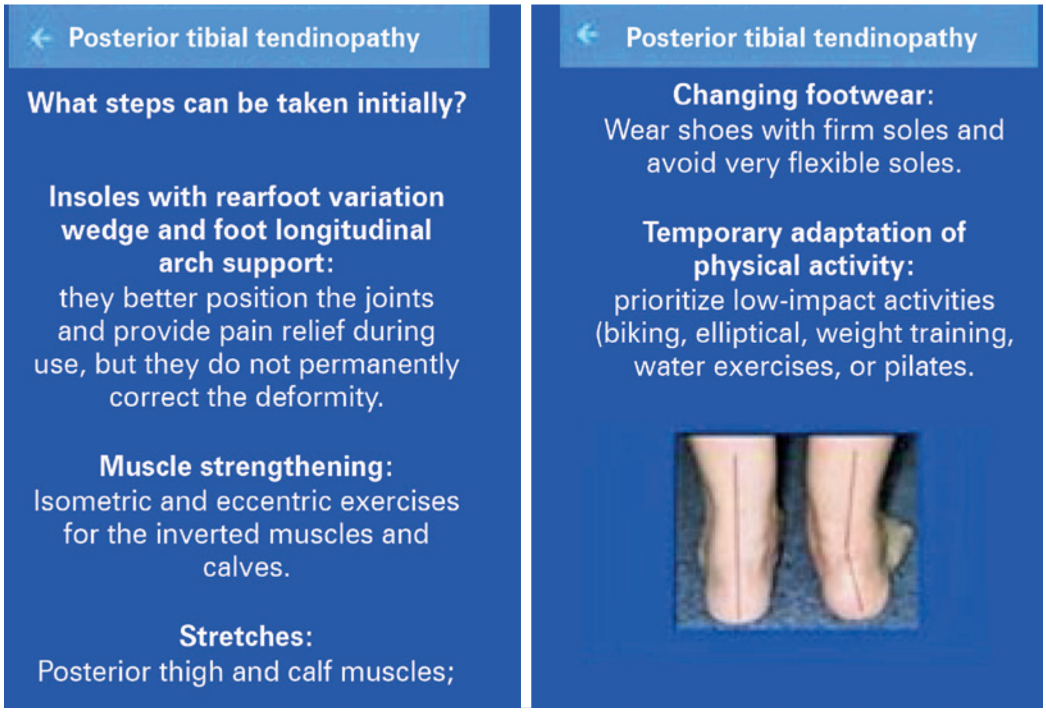

Figure 7. Informative screens about the condition and appointment shortcuts.
Source: App Pés com Dor (Portuguese).

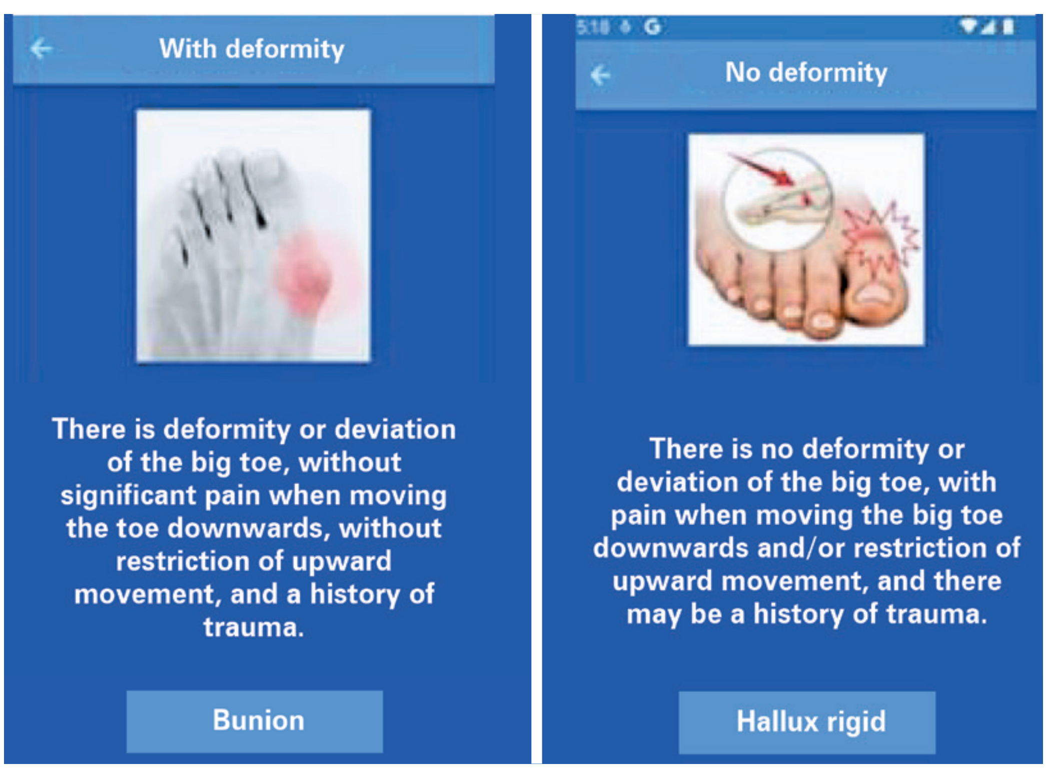

Figure 8. Flowchart screens for conditions affecting the hallux (Valgus vs. rigid).
Source: App Pés com Dor (Portuguese).

and impairing their professional and sporting activities. Continuous population education through advertising tools, applications, or software, like the one studied here, can effectively improve patient's physical and mental health indices and overall quality of life.

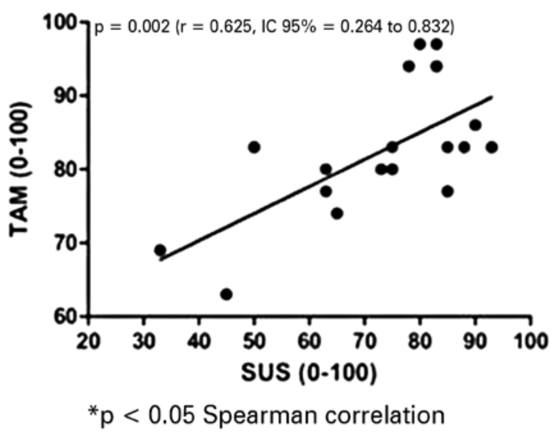

Figure 9. Correlation between usability and acceptance.

The APP showed a low overall agreement (40.9%) between its results and diagnoses provided by a foot specialist orthopedic doctor, but some findings deserve attention. When the selected condition was hallux valgus, an easily identifiable and well-known deformity, the agreement was 100%. Despite the low sample size (n = 1), larger samples would likely follow this trend.

When the selected condition was metatarsalgia, the agreement rate was 66.67%. In the single case of divergence, the doctor diagnosed lateral foot overload, a condition often associated with metatarsalgia. This limitation of the software in analyzing associations between multiple conditions might have influenced the results. When combining forefoot conditions (hallux valgus and metatarsalgia), the agreement between the software and the orthopedic doctor reached 75% (Hallux Valgus 1:1 and metatarsalgia 2:3). This suggests the APP might be more accurate for forefoot conditions.

Plantar fasciitis, suggested by the APP in four cases, corresponded to the medical diagnosis in three patients (75%). The diagnosis was plantar clavus (a rare tumor-like lesion) in the single case of divergence. This condition likely falls outside the APP's decision flowchart, suggesting that larger samples would maintain similar concordance rates.

Table 1. Description of the pain scale and correlation between the conditions suggested by the APP and the medical consultation diagnosis

Pain Scale (1 to 10)	Condition suggested by the APP	Medical consultation diagnosis
5	Fibular tendinitis	Lateral foot overload
6	Plantar fasciitis	Plantar fasciitis
6	Unspecified condition	Lateral foot overload
6	Lateral foot overload	Posterior tibial tendinitis
4	Metatarsalgia	Metatarsalgia
5	Unspecified condition	Tumoral lesion (Not included in the APP)
4	Metatarsalgia	Metatarsalgia
6	Plantar fasciitis	Plantar fasciitis
8	Unspecified condition	Ankle Instability (Not included in the APP)
6	Calcaneal tendinitis	Posterior tibial tendinitis
8	Lateral foot overload	Plantar fasciitis
8	Plantar fasciitis	Plantar fasciitis
10	Calcaneal tendinitis	Plantar fasciitis
3	Calcaneal tendinitis	Calcaneal tendinitis
8	Hallux valgus	Hallux valgus
10	Plantar fasciitis	Plantar clavus (Not included in the APP)
8	Unspecified condition	Metatarsalgia + lateral overload (Multiple conditions)
6	Posterior tibial tendinopathy	Calcaneal tendon rupture (Not included in the APP)
9	Lateral foot overload	Lateral foot overload
6	Metatarsalgia	Lateral foot overload
6	Fibular tendinitis	Ankle instability (Not included in the APP)
7	Unspecified condition	Metatarsalgia + lateral overload (Multiple conditions)

Calcaneal tendon tendinitis showed agreement in two out of three cases (66.67%). The divergent case was linked to plantar fasciitis, a neighboring condition often associated with calcaneal tendinitis, as their causal factors are similar. The divergence might result from the APP analyzing only a single condition, not from true incompatibility. The initial management measures for both conditions are similar, so when combining hindfoot/heel conditions (Plantar fasciitis and calcaneal tendon tendinitis), the agreement was 85.6% (6 out of 7 patients).

Table 2. Percentage analysis of pain intensity, the condition suggested by the APP, and the medical diagnosis. Data expressed in absolute and percentage frequencies.

Pain Scale (0-10)	n (%)
3	1 (4.5%)
4	1 (4.5%)
5	2 (9.1%)
6	8 (36.4%)
7	1 (4.5%)
8	6 (27.3%)
10	2 (9.1%)
Suggested diagnosis	
Unspecified condition	5 (22.7%)
Plantar fasciitis	4 (18.2%)
Hallux valgus	1 (4.5%)
Metatarsalgia	3 (13.6%)
Lateral foot overload	3 (13.6%)
Calcaneal tendinitis	3 (13.6%)
Fibular tendinitis	2 (9.1%)
Posterior tibial tendinopathy	1 (4.5%)
Real diagnosis	
Plantar clavus	1 (4.5%)
Plantar fasciitis	4 (18.2%)
Hallux valgus	1 (4.5%)
Ankle instability	2 (9.1%)
Tumoral lesion	1 (4.5%)
Metatarsalgia	2 (9.1%)
Metatarsalgia + Lateral overload	2 (9.1%)
Calcaneal tendon rupture	1 (4.5%)
Lateral foot overload	4 (18.2%)
Calcaneal tendinitis	2 (9.1%)
Posterior tibial tendinitis	2 (9.1%)
Diagnostic agreement	**9 (40.9%)**
SUS	
SUS ≤ 70%	6 (27.3%)
SUS > 70%	16 (72.7%)
TAM	
TAM ≤ 70%	2 (9.1%)
TAM > 70%	20 (90.9%)

These results demonstrate that the APP can be highly accurate for specific and common foot conditions. By grouping some conditions into syndromic diagnoses with overlapping initial management strategies, such as heel conditions, the APP's accuracy could be improved. This would provide greater pain relief for patients while waiting for specialist consultations, which can take months or even years, depending on their location and healthcare system (public or private).

This software is similar to existing health-related foot care APPS, such as those designed for diabetic foot care. These APPS recommend foot care measures, self-assessment for diabetic neuropathy complications, and personalized foot and ankle exercises[31]. A similar approach was used to support nurses in decision-making for the topical treatment of diabetic foot ulcers[32].

Structurally, another APP is similar to this study's application, utilizing the expertise of specialists in diabetic foot care and providing educational content through animated videos and adaptive learning for patients and caregivers[33].

Comparing this APP to others in healthcare, similarities in usability (classified as good and acceptable) were found with APPS like "MY PICC"[34]. Moreover, as highlighted in this study, the importance of technologies that facilitate patient access to information was observed, aligning with innovations in the healthcare field reported in literature reviews[35,36]. Similar results were observed in a study comparing the acceptance of a health data storage APP, showing good user receptivity while highlighting the need for further studies[37].

Thus, despite positive results and similarities with other studies, further research and analysis are needed to generalize findings to larger populations and ensure greater alignment with general population needs. According to the SUS method, ten questions were used for the usability assessment, as shown in Table 3. Eighteen people (equivalent to 81.8%) voted that they agreed or strongly agreed with the question, "I think I would like to use this application frequently." Nineteen (86.3%) responded that they disagreed or strongly disagreed with "I found this application unnecessarily complex." Twenty (90%) agreed or strongly agreed with "I find the application easy to use." As for "I think I would need technical support to use this application," 15 (68%) responded that they disagreed or strongly disagreed, while four (18.2%) neither agreed nor disagreed. Twenty (90%) agreed or strongly agreed with "I thought the various features of the application were well integrated." Sixteen (72%) disagreed or strongly disagreed with "I thought there was a lot of inconsistency in the application," with four (18.2%) neither agreeing nor disagreeing. Nineteen (86.3%) responded as agreeing or strongly agreeing to "I imagine most people can learn to use this application very quickly." The same number responded as disagreeing or strongly disagreeing, saying, "I found the application very complicated to use." Sixteen (72%) felt very confident using the APP, while 18 (81%) disagreed with "I had to learn several things before I could start using this application."

Table 3. User perception of the application's usability. Data expressed as absolute and percentage frequencies.

Question	Mean ± SD	Cronbach's α	Likert Scale				
			1	2	3	4	5
SUS	**73.18**	**0.850**					
S1. I think I would like to use this application frequently.	3.91 ± 0.68	0.873	0 (0.0%)	1 (4.5%)	3 (13.6%)	15 (68.2%)	3 (13.6%)
S2. I found this application unnecessarily complex.	1.91 ± 0.87	0.756	7 (31.8%)	12 (54.5%)	1 (4.5%)	2 (9.1%)	0 (0.0%)
S3. I found the application easy to use.	4.27 ± 0.77	0.838	0 (0.0%)	1 (4.5%)	1 (4.5%)	11 (50.0%)	9 (40.9%)
S4. I think I would need technical assistance to use this application.	2.09 ± 1.06	0.860	8 (36.4%)	7 (31.8%)	4 (18.2%)	3 (13.6%)	0 (0.0%)
S5. I thought the various features of the application were well integrated.	3.77 ± 0.61	0.836	0 (0.0%)	0 (0.0%)	1 (4.5%)	4 (18.2%)	16 (72.7%)
S6. I thought there was a lot of inconsistency in the application.	2.23 ± 0.97	0.824	4 (18.2%)	12 (54.5%)	4 (18.2%)	1 (4.5%)	1 (4.5%)
S7. I imagine most people can learn to use this application very quickly.	3.91 ± 0.61	0.813	0 (0.0%)	1 (4.5%)	2 (9.1%)	17 (77.3%)	2 (9.1%)
S8. I found the application very complicated to use.	2.00 ± 0.82	0.758	5 (22.7%)	14 (63.6%)	1 (4.5%)	2 (9.1%)	0 (0.0%)
S9. I felt very confident using this application.	3.59 ± 0.91	0.851	1 (4.5%)	2 (9.1%)	3 (13.6%)	15 (68.2%)	1 (4.5%)
S10. I had to learn several things before I could start using this application.	1.95 ± 0.90	0.776	7 (31.8%)	11 (50.0%)	2 (9.1%)	2 (9.1%)	0 (0.0%)

Table 4. Analysis of user acceptance of the application. Data expressed as mean ± SD or absolute and percentage frequencies.

Question	Mean ± SD	Cronbach's α	Likert Scale				
			1	2	3	4	5
T1. I consider the video with the 3D foot model and pain site indicators easy to understand.	4.18 ± 0.59	0.775	0 (0.0%)	0 (0.0%)	2 (9.1%)	14 (63.6%)	6 (27.3%)
T2. I consider the flowchart used by the application easy to understand.	4.00 ± 0.69	0.760	0 (0.0%)	1 (4.5%)	2 (9.1%)	15 (68.2%)	4 (18.2%)
T3. I consider the language used in explaining the conditions easy to understand.	4.14 ± 0.56	0.762	0 (0.0%)	0 (0.0%)	2 (9.1%)	15 (68.2%)	5 (22.7%)
T4. I consider it a useful technology for informing about foot-related conditions.	3.95 ± 0.95	0.857	1 (4.5%)	1 (4.5%)	1 (4.5%)	14 (63.6%)	5 (22.7%)
T5. The application contributes to understanding foot pain.	4.23 ± 0.53	0.740	0 (0.0%)	0 (0.0%)	1 (4.5%)	15 (68.2%)	6 (27.3%)
T6. I believe that disseminating the application to the general population will help improve foot pain.	4.23 ± 0.53	0.740	0 (0.0%)	0 (0.0%)	1 (4.5%)	15 (68.2%)	6 (27.3%)
T7. I believe the information about the prevention of foot conditions will reduce the number of people affected.	4.18 ± 0.50	0.845	0 (0.0%)	0 (0.0%)	1 (4.5%)	16 (72.7%)	5 (22.7%)

Regarding the TAM assessment in Table 4, 20 (90%) agreed or strongly agreed with the statement, "I consider the video with the 3D foot model and pain site indicators easy to understand". Nineteen (86.3%) agreed or strongly agreed with "I consider the flowchart used by the application easy to understand." Twenty (90%) agreed or strongly agreed with "I consider the language used in explaining diseases to be easily accessible." Nineteen (86.3%) agreed or strongly agreed with "I consider it a useful technology for informing about foot-related conditions." Twenty-one (95.4%) strongly agreed with "The application contributes to understanding foot pain." Likewise, the same number responded in the same way to "I believe that disseminating the application to the general population will help improve foot pain" and "I believe the information about the prevention of foot conditions will reduce the number of people affected."

Conclusion

An informative APP was developed with good accuracy for some foot conditions, although it showed low overall agreement for the target audience. Further studies are needed to improve the APP's accuracy and develop better flowcharts. The usability and acceptance evaluation of the platform demonstrated the APP's relevance in educating and empowering users, guiding them about the main foot conditions while waiting for a specialist consultation, which remains indispensable and irreplaceable.

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Original Article

Maisonneuve fractures and ligament injuries: how to stabilize the ankle?

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Abstract

Objectives: Quantify syndesmosis and deltoid injuries in Maisonneuve Fractures, identify which ligament is the most efficient in ankle stabilization, quantify the need for joint ligament repairs, and certify the ankle stability without fracture fixation.

Methods: Between 2007 and 2022, a total of 70 patients were included-40 with acute trauma and 30 with chronic trauma; the mean age was 35.57 years. Fifty-one patients were randomized into Groups I and II. Patients in Group I (26) received syndesmosis repair, and patients in Group II (25) received deltoid repair. Group I also received a deltoid suture when the patients were still unstable, and Group II received syndesmosis repair. Chronic patients, in addition to fixation, also received syndesmosis reconstruction.

Results: Ligament injuries were present in 100% of the ankles, 72.86% joint injuries, and 27.14% isolated. Syndesmosis repair stabilized 61 ankles (92.42%), and deltoid repair nine ankles (16.98%). Joint repairs were performed on 28 ankles (40%). Stable ankles without fibular fracture fixation totaled 68 (97.15%). The syndesmosis repair in Group I was efficient in 80.76%, and in Group II, the deltoid repair in 13.73%. In non-randomized patients (19), 100% of the repairs alone were efficient.

Conclusion: Our results concluded that the Maisonneuve fractures had 100% associated ligament injuries. Fixing the syndesmosis was significantly more efficient than repairing the deltoid in stabilizing the ankle. Repairs of both ligaments were necessary in 40% of the ankles. Stabilizing the ankle does not require addressing the high fibular fracture.

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

Keywords: Maisonneuve fracture; Ankle joint; Ankle.

Introduction

Maisonneuve fracture, described in 1840, involves the proximal fibula, syndesmosis, and deltoid ligament injuries[1]. Lauge-Hansen[2] describes it in terms of external pronation and rotation, and Pankovich[3] describes it in five stages with different extents of damage. Bartoníček et al.[4] reported syndesmosis injuries (100%), posterior malleolus fracture (80%), and deltoid injuries (50%) in 54 patients. The impairment of ankle function depends on the extent of the associated injuries[2-7]. Less frequent injuries are also in the literature[8-10]. Instability related to the severity of ligament injuries is recorded in the classifications[2-5,11]. The Maisonneuve fracture is described as very unstable[3]. Pre- and intraoperative clinical and radiographic tests identify instability and the necessary ligament repair[4,12,13]. The literature lacks precise quantification regarding the percentages of isolated or combined ankle injuries and the effectiveness of their respective repairs in achieving ankle stabilization. Treatment methods vary, with conservative and surgical options[3,7].

Some authors do not value ligament injuries and prefer conservative treatment[3,10,14]. Other authors consider this fracture unstable and recommend its surgical treatment[3,4,7,15-17]. Various surgical treatment options exist, but there is still

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no consensus in the literature regarding key aspects. These include whether or not to fix the fracture, using percutaneous surgery with or without ligament repairs, and the timing and method for syndesmosis fixation[4,14-26].

As described by some authors, optimal ankle function requires bone consolidation, ligament stability, and proper positioning of the fibula within the syndesmotic notch[4,6,7,17-20]. Non-uniform reports of the importance and forms of these ligament repairs in the literature motivated us to conduct this study[3,4,6,14-26].

The objectives of this prospective, quasi-randomized study are to quantify syndesmosis and deltoid injuries in Maisonneuve Fractures, identify which ligament is the most efficient in ankle stabilization, quantify the need for joint ligament repairs, and certify the ankle stability without fracture fixation.

Methods

This study included 70 patients (49 men and 21 women) with a mean age of 35.57 years, comprising 40 acute and 30 chronic cases, all diagnosed with Maisonneuve fractures and treated between February 2007 and November 2022. Inclusion criteria encompassed patients with indirect trauma and an oblique or spiral fracture in the proximal third of the fibula, while those with direct trauma and horizontal fractures were excluded. Additionally, three patients with the same trauma mechanism but without visible fibular fractures were included.

Patients diagnosed with Maisonneuve fractures in the emergency department underwent a thorough ankle examination and radiographic assessment. In cases of pain, anteroposterior (AP) stress radiography was performed in pronation and external rotation, applying force within the patient's pain tolerance, without anesthesia. Patients exhibiting talar inclination, an increased medial clear space of the ankle (greater than 4 mm), or lateral displacement of the talus were referred for surgery.

Patients with a delayed diagnosis were evaluated at the hospital's Foot and Ankle Outpatient Clinic due to persistent pain and/or ankle instability following three months of conservative treatment. Clinical and radiographic assessments confirmed the diagnosis of Maisonneuve fracture and ankle instability, leading to their surgical referral.

In the operating room under spinal anesthesia, AP stress radiography was repeated to confirm ligament injuries. The 51 patients with joint syndesmosis and deltoid ligament injuries were divided into Groups I (26 patients) and Group II (25 patients) and treated randomly. Patients with isolated deltoid injuries (02) or syndesmosis (17) were not randomized.

Acute patients in Group I underwent percutaneous syndesmosis fixation using one or two 4.5 mm cortical screws, with a smooth tunnel in the fibula and fixation to one or two tibial cortices. Chronic patients in Group I underwent open syndesmosis reconstruction using fibular and tibial periosteal flaps, secured with two trans-syndesmotic screws fixing four cortical screws. Patients in Group II underwent deltoid ligament repair along with the anteromedial capsule, using transosseous sutures or anchors placed in the medial malleolus or the talar neck. After the initial procedure in each group, a new AP stress radiograph was performed. If instability persisted in Group I, medial capsule/ligament repair was also performed. For Group II, if the ankle remained unstable, acute cases underwent syndesmosis fixation, while chronic cases required syndesmosis reconstruction and fixation. Additionally, two acute cases in Group II had syndesmosis fixation performed despite medial repair already achieving stabilization.

The fibula fracture was addressed and surgically fixed in two chronic patients with unstable ankles-one presenting with common fibular nerve compressive syndrome and the other with pseudoarthrosis and fibular shortening. After surgery, all ankles underwent AP stress radiographs to assess the stability achieved. Postoperatively, all patients were immobilized for six weeks without weight-bearing. Skin stitches were removed after three weeks. Full weight-bearing was allowed at the end of the sixth week, with walking permitted for one hour per day starting from the third postoperative month, as tolerated by each patient. Syndesmosis screws were removed after eight months, at which point impact activities were authorized. Clinical and radiographic follow-ups were conducted every two months, with a final evaluation performed at least 12 months postoperatively. The ankle and hindfoot American Orthopaedic Foot and Ankle Society (AOFAS) score and the Visual Analog Scale (VAS) were used as assessment criteria. To compare treatment efficacy between groups, statistical analysis was conducted using the Chi-square test, with a significance level set at 5%.

Results

Traffic trauma was the most common cause of injury, followed by sports-related incidents, domestic accidents, and professional ballet training. Ligament injuries were present in all ankles, either as isolated or combined injuries (Table 1).

Syndesmosis repair was performed in 66 ankles, while deltoid ligament in 53. The percentages and methods of repair are shown in Table 2.

Table 1. Types of trauma and incidences of ligament injuries

Category	Details
Cause	- Traffic accidents: 27 cases (38.57%) - Sports-related incidents: 23 cases (32.85%) - Domestic accidents: 19 cases (27.14%) - Professional ballet training: 1 case (1.42%)
Ligament injuries	- Present in 100% of ankles - 51 ankles with combined injuries (72.85%) - 19 ankles with isolated injuries (27.14%) - 2 Deltoid e 17 syndesmosis

Syndesmosis repair successfully stabilized 61 ankles but was unsuccessful in five cases. Deltoid ligament repair was effective in only nine cases, while 44 repairs were unsuccessful. Group I (Syndesmosis repair) had an 80.76% success rate, with 19.23% of repairs failing. Group II (Deltoid ligament repair) had a significantly lower success rate of 8%, with 92% of repairs failing (Table 3).

Joint repair of both ligaments was necessary in 28 ankles (40%). In the 19 non-randomized patients, isolated repairs were 100% successful. Stable ankles at the end of surgery without high fibular fracture fixation totaled 68 (97.15%).

Five ankles in Group I (four acute and one chronic) required additional deltoid repair due to persistent instability. Deltoid repair successfully stabilized two acute Group II ankles and two non-randomized cases. Successful deltoid repairs: 6 using anchors, 3 using transosseous sutures. Unsuccessful deltoid repairs: 23 total-5 using anchors, 18 using transosseous sutures. All ankles at the end of surgery were submitted to AP stress radiograph and showed stability (Table 4).

Table 2. Percentages and methods of ligament repairs

Category	Details
Repairs	- Syndesmosis repaired in 66 ankles - Deltoid ligament repaired in 53 ankles
Syndesmosis repair	- 57 ankles with 2 screws/4 cortices (81.44%) - 7 ankles com 1 screw/4 cortices (10%) - 6 ankles com 2 screws/3 cortices (8.57%)
Deltoid repair	- 12 ankles with anchors (22.64%) - 41 ankles with transosseous sutures (77.36%)

Table 3. Percentages of efficiency of ligament repairs

Category	Details
Repair efficiency	- Syndesmosis: successful in 61 ankles (92.42%), unsuccessful in 5 (7.57%) - Deltoid: successful in 9 ankles (16.98%), unsuccessful in 44 (83.02%)
Results per Group	- Group I (syndesmosis): successful in 80.76%, unsuccessful in 19.23% - Grupo II (deltoid): successful in 8%, unsuccessful in 92%

One chronic patient with joint repairs developed late instability, experiencing occasional ankle "falsehood" at 12 months postoperatively. Clinical and radiographic tests showed syndesmosis instability. At 15 months post-operative, incipient signs of ankle arthrosis and occasional pain were noted. The patient underwent reconstruction and syndesmosis fixation, and by 12 months post-revision surgery, the ankle was stable but with some residual pain.

Syndesmosis repair was significantly more effective than deltoid ligament repair (p = 0.00001) in ankle stabilization-in both the complete series (Table 5) and group comparisons (Table 6). Functional outcomes at 12 months postoperatively are detailed in Tables 7 and 8.

Discussion

We align with authors who classify Maisonneuve fracture as an ankle injury due to the associated injuries occurring at the ankle[1-6]. The external rotation force initially impacts the ankle before propagating to the proximal fibula, directly compromising ankle function due to sustained injuries[2-5,9]. Acute patients typically present ankle-related complaints during their initial visit. Undiagnosed patients often seek further medical care due to persistent ankle dysfunction. Our series has 30 patients whose diagnosis was made late. The incidence of Maisonneuve fractures is difficult to determine due to frequent underdiagnosis, with reported rates ranging from 1% to 11% in the literature[3-7,10]. Our service identified an incidence of 7.82%, which we consider high, aligning with Pankovich's reported rate of 5%[3]. Our study presents a larger case series than Bartoníček et al.[4], who described 54 acute cases, as it also includes 30 chronic patients. The predominance of male patients (49 men and 21 women) is consistent with data reported in the literature[21].

We documented one case of pseudoarthrosis and one of delayed consolidation, findings not commonly reported in the literature. However, we believe that bone consolidation alone does not guarantee a favorable outcome, as optimal ankle function also depends on the stability provided by ligament repairs, as recommended by Stufkens et al.[7].

Syndesmosis and deltoid ligament injuries are reported in the literature with varying prevalence and diagnostic methods[1-5]. Pakarinen et al.[12] used external rotation stress

Table 4. Efficiency of syndesmosis and deltoid repairs

	Ligament injuries	Nº patients	Repairs	Successful	p
Combined 72.85%	Syndesmosis + Deltoid	51	Syndesmosis = 66	61 – 92.42%	0.00001
			Deltid = 53	09 – 16.98%	
Isolated 27.14%	Syndesmosis	17	Treated separately		
	Deltoid	02			
100%	70	70	70 patients	Stable ankles	
			100% ligament repairs	70 = 100%	
2.85%		2	With an approach to fibula fracture		

without foot pronation but concluded that this method alone is insufficient for diagnosing syndesmosis instability intraoperatively. Stoffel et al.[13] described the same test to identify deltoid ligament injuries, stating that it is more effective for diagnosing syndesmosis injuries. Our study systematically assessed syndesmosis and deltoid ligament injuries through clinical and radiographic examinations, following the methods described by Bartoníček et al.[4] and Puddu et al.[22]. To diagnose ligament injuries, we performed simultaneous pronation and external rotation stress tests. Stress radiographs in the emergency room were conducted without anesthesia, with a medial clear space opening greater than 4 mm considered indicative of deltoid ligament injury[4,16].

Table 5. Efficiency of repairs – within Groups 1 and 2

Group	Successful	Unsuccessful	p
Syndesmosis – GROUP I	80.76%	19.23%	0.00001
Deltoid – GROUP II	8%	92%	

Table 6. Joint repairs of both ligaments in the same ankle

	Patients	Percentage
Patients who required repairs of both ligaments for ankle stabilization	28	40%

All patients in this series had confirmed isolated and/or combined ligament injuries intraoperatively, consistent with findings reported by Bartoníček et al.[4].

The treatment of Maisonneuve fractures and their associated injuries remains non-uniform, with few authors advocating for direct fibular fixation[17]. Deltoid ligament injuries are often undervalued, and some authors, including Pankovich[3], Merrill[14], Zeegers et al.[18], and Harper[20], do not repair them. Conversely, Weber[5], Stufkens et al.[7], Johnson et al.[19], and Kim et al.[26] recommend deltoid ligament repair to ensure ankle stabilization and prevent late dysfunction.

Numerous authors recommend syndesmosis fixation[4-7,16,27], but there is no consensus on the method. Percutaneous and open fixation techniques are commonly reported. Various methods include one or two screws (3.5 mm or 4.5 mm), securing three or four cortices, or Suture Button fixation (one or two buttons)[2,4-7,15,16,21-27].

All 70 patients were treated surgically, and all ligament injuries were repaired. High fibular fractures were not directly addressed, as described by Stufkens et al.[7]. Deltoid ligament repair was performed, following recommendations from multiple authors[4,7,19,26], using anchors where available or transosseous sutures. Our results indicate a high failure rate (83.02%) for both suture methods, with anchors showing superior effectiveness. However, due to unequal sample sizes between treatment methods, a definitive conclusion regarding the superiority of anchors cannot be drawn.

Table 7. Results of the evaluation with the AOFAS criteria

	AOFAS PREOPERATIVE					AOFAS POSTOPERATIVE				
	Mean	n	SD	Min	Max	Mean	n	SD	Min	Max
ACUTE	50.25	40	7.33	25	60	87.00	40	6.28	70	100
I	49.21	19	8.54	25	60	87.37	19	7.33	70	100
II	51.19	21	6.10	35	60	86.67	21	5.32	75	95
CHRONIC	44.03	30	6.86	30	60	86.83	30	5.80	75	95
I	45.63	19	7.14	35	60	86.58	19	5.79	75	95
II	41.27	11	5.61	30	50	87.27	11	6.07	75	95
Total	47.59	70	7.73	25	60	86.93	70	6.04	70	100

AOFAS: The ankle and hindfoot American Orthopaedic Foot and Ankle Society; SD: Standard deviation; Min: Minimum; Max: Maximum.

Table 8. Results of the evaluation with the VAS criteria

	VAS PREOPERATIVE					VAS POSTOPERATIVE				
	Mean	n	SD	Min	Max	Mean	n	SD	Min	Max
ACUTE	7.78	40	1.42	5	10	1.55	40	1.06	0	5
I	7.89	19	1.63	5	10	1.53	19	1.26	0	5
II	7.67	21	1.24	6	10	1.57	21	0.87	0	4
CHRONIC	8.13	30	1.04	5	10	2.07	30	1.28	1	7
I	8.05	19	1.18	5	10	2.16	19	1.46	1	7
II	8.27	11	0.79	7	10	1.91	11	0.94	1	4
Total	7.93	70	1.28	5	10	1.77	70	1.18	0	7

VAS: Visual Analog Scale; SD: Standard deviation; Min: Minimum; Max: Maximum.

Acute syndesmosis injuries (40 cases) were fixed percutaneously with trans-syndesmotic screws, as reported by Obeid et al.[15], Sproule et al.[16], and Hansen et al.[22]. Chronic lesions (30 cases) were reconstructed with periosteal flaps and also underwent fixation. The majority of cases were treated using two 4.5 mm screws fixing four cortices, as recommended by Stufkens et al.[7] and Hansen et al.[22]. Our results align with the literature, which suggests no significant differences in syndesmosis fixation methods using screws[15,16,22]. Suture Button fixation was not used, as it was unavailable in our service. However, we acknowledge its importance-Shimozono et al.[21], in a meta-analysis, highlighted its superior outcomes and rare complications, recommending it for syndesmosis stabilization.

The method of syndesmosis stabilization is important, but not indispensable. However, we strongly emphasize that proper fibular positioning within the syndesmotic notch is essential, a principle reinforced by multiple authors[4,6,7,17,18,21-24,27].

It is possible to achieve ankle stability and good functional outcomes in Maisonneuve fractures through appropriate ligament repairs, without directly addressing the fibula, as shown by the AOFAS and VAS scores recorded in our study.

The strengths of our study are the systematic identification of ligament injuries, ensuring comprehensive assessment and treatment, and using stress radiographs during surgery to confirm final ankle stability.

Our study has some limitations in the heterogeneous patient population, including both acute and chronic cases, which underwent different syndesmosis treatments, and the surgeries were performed by multiple surgeons, leading to variability in surgical techniques.

Conclusion

Our results concluded that the Maisonneuve fractures had 100% associated ligament injuries. Fixing the syndesmosis was significantly more efficient than repairing the deltoid in stabilizing the ankle. Repairs of both ligaments were necessary in 40% of the ankles. Stabilizing the ankle does not require addressing the high fibular fracture.

Authors' contributions: Each author contributed individually and significantly to the development of this article: JVP *(https://orcid.org/0000-0003-1445-9464) Conceived and planned the activities that led to the study, performed the surgeries, interpreted the results of the study, wrote the article, participated in the review process; CABP *(https://orcid.org/0000-0003-0401-1164) Conceived and planned the activities that led to the study, performed the surgeries, interpreted the results of the study, wrote the article, participated in the review process; FSB *(https://orcid.org/0000-0001-6073-8523) Conceived and planned the activities that led to the study participated in the review process; EMT *(https://orcid.org/0009-0005-5078-4434) Conceived and planned the activities that led to the study participated in the review process; RSP *(https://orcid.org/0000-0003-1702-1302) Conceived and planned the activities that led to the study participated in the review process; BHBP *(https://orcid.org/0009-0001-5534-8018) Conceived and planned the activities that led to the study, participated in the review process. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Original Article

Optimization of MRI measurements of calf muscle atrophy following acute Achilles tendon rupture

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Abstract

Objective: Investigate whether single slice cross- sectional area (CSA) measurement could be used as a surrogate for volumetric measurement on magnetic resonance imaging (MRI) in evaluating calf muscle atrophy after Achilles tendon rupture (ATR). We hypothesized that atrophy estimated by single slice CSA measurement had an R-squared (R^2) value above 0.7 when compared to volumetric measurements.

Methods: This was a cross-sectional study of patients one year after ATR. An MRI of both calves was performed. Muscle volume was calculated by measuring CSA of the muscles of the triceps surae and the deep flexors on axial slices every 2 cm. The limb symmetry index (LSI) was used to estimate atrophy. The two methods for assessing atrophy, single slice CSA and volumetric measurement, were compared by fitting a linear regression model and calculating the R^2-value.

Results: The strongest correlation was obtained when measuring CSA of the triceps surae (R^2 = 0.780), soleus (R^2 = 0.636), medial gastrocnemius (R^2 = 0.612) and lateral gastrocnemius (R^2 = 0.556) 26 cm above talus, and the deep flexors (R^2 = 0.493) 14 cm above talus.

Conclusions: Cross- sectional area measurement on a single MRI slice can be applied as a surrogate for volumetric measurements when investigating atrophy of the triceps surae muscle group as a whole. However, this approach is not suitable when investigating the individual parts of the muscle.

Level of evidence III, Cross-sectional comparative study.

Keywords: Achilles tendon; Rupture; Magnetic Resonance Imaging; Muscular atrophy; Cross-sectional studies.

Introduction

Changes in calf muscle volume are common after acute Achilles tendon rupture (ATR)[1]. Muscular change following ATR is affected by a complex combination of tendon elongation, type of rehabilitation, and sedentary lifestyle[2]. Muscle atrophy has been reported as a common long-term problem in ATR causing changes in gait pattern and reduced total concentric plantar flexion power[3-5].

Quantifying muscle compartment size on magnetic resonance imaging (MRI) can be performed in two ways: volumetric or cross-sectional area (CSA) measurement. Volumetric measurement is time-consuming and requires more data collection than CSA measurement[6,7].

The current literature, on optimizing the process of muscle volume assessment, suggests that the volume of the individual muscles of the triceps surae can be estimated using two primary methods: 1) calculating the muscle length byand the largest measured CSA[8-10] or 2) converting the average of the largest CSA and the CSAs proximal and distal to the largest CSA to a volume using a fitted regression model[11]. The commonality between the two methods is the need for measurements on several slices and/or a view of the complete muscle.

Since not all MRIs provide a field of view of the full length of the soleus and gastrocnemius muscles, we aimed to simplify the method of volume expression further by applying the

Study performed at the Sports Orthopedic Research Center - Copenhagen (SORC-C), Hvidovre Hospital, Hvidovre, Denmark.

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measurement of one single slice to estimate the muscle volume of the individual muscles in the triceps surae.

The purpose of the study is to investigate the possible replacement of volumetric measurement by single slice CSA measurement when examining the volumetric changes to the calf muscles after acute ATR utilizing MRI. Using volumetric measurements on MRI as the gold standard, we hypothesized that atrophy estimated by single- slice CSA measurements of the individual muscles had an R-squared (R^2) value above 0.7 when compared to the golden standard method.

Methods

The study was performed as a cross-sectional study investigating patients one year after acute ATR. The study was reported following the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) checklist[12].

Study setup

An MRI was performed one year after ATR on the injured and the uninjured lower leg. Atrophy of the injured leg was expressed as the relative atrophy compared to the uninjured leg and was calculated using the limb symmetry index (LSI). Relative atrophy or LSI was defined as the scores of the injured leg divided by the scores of the uninjured leg presented as a percentage:

$$\text{Limb symetry index (LSI)} = \frac{\text{injured leg}}{\text{uninjured leg}} \cdot 100$$

The LSI values determined by volumetric measurement were then compared with those determined by single slice CSA measurement.

Study participants

Patients were recruited through an ongoing randomized controlled trial investigating functional and patient-reported outcomes after acute ATR[13,14]. The inclusion criteria were: age 18 to 65, examination in the outpatient clinic within four days after injury, total ATR, initial treatment with split plaster cast with the ankle in maximal plantar flexion started within 24 hours after injury, ability to attend rehabilitation and post examinations, and ability to speak and understand Danish. The exclusion criteria were previous ATR in either leg, examination in the outpatient clinic later than four days after injury, tendon rupture at either insertion, corticosteroid or fluroquinolone treatment within the last six months, diabetes medical treatment, prior injury resulting in reduced function of the legs, contraindication for surgery, American Society of Anaesthesiologists (ASA) score ≥ 3. All patients were given, oral and written, information concerning the project before informed consent was obtained.

MRI measurements

The MRI measurements were determined by measuring and studying the three muscles of the triceps surae (soleus, medial gastrocnemius, and lateral gastrocnemius), both individually and the muscle group as a whole, represented by the sum of the three muscles. The deep flexors (flexor hallucis longus, flexor digitorum longus, and tibialis posterior) were measured and studied as one unified group.

The scans were conducted on a 1.5T MRI system (Magnetom Avanto, Siemens, Erlangen, Germany). The MRI sequence protocol applied was a 2D gradient echo sequence (Siemens DESS (Dual Echo Steady State) package). This protocol enabled a reconstruction of the scan, constructing 1 mm axial slices with 1 mm interslice distance, thereby creating a 2 mm distance between each slice. Both calves were scanned from just inferior to the heel and as proximal as our field of view allowed. The scans were performed with patients in the supine position and with the ankle in neutral position (90 degrees) secured by custom-made braces.

The CSA was measured manually by marking the muscle compartments individually using the "closed polygon"" function in OsiriX Lite© version 12.0 (Figure 1). The most distal border of the measurement was defined by the most cranial aspect of the talus bone. The measurement started at the most proximal axial slide where the talus was visualized, being the distal reference slide. From there, CSA was measured on every 10th slice (20 mm intervals) cranially. When a muscle compartment originated within this interval, the part of the muscle distal to the first CSA measurement of the muscle compartment was not included in the volume. The measurements were performed by two investigators (ABO and IEH). ABO measured 18 subjects and IEH 36 subjects. Conformity of the measuring method was achieved through a thorough, written, step-by-step examination protocol. Subsequently, IEH and ABO performed one measurement of a scanning image together to adjust for possible differences.

The proximal origin of the gastrocnemius muscles at the femoral condyles was not visualized as no MRI coil allowed for a field of view of the necessary length in the Magnetom Avanto MRI scanner. Consequently, the proximal border of the CSA measurement was defined as the most proximal 20 mm interval section in which no blurring of the picture was present. By involving the same number of slices with 20 mm intervals on both lower legs, we ensured that the distance measured from the talus was the same on the injured and uninjured leg.

Calculation of muscle volume – the gold standard

The muscle volume between two CSAs was calculated as cones with irregular bottoms using the formula: Volume = $h/3 \times (A_1 + \sqrt{(A_1 \times A_2)} + A_2)$, where h is the height of one cone and equals 20 mm, while A_1 and A_2 are the bottom and top of the cone, respectively, being the CSA measurements of the individual muscle compartments. The muscle volume of the individual muscles was then determined by adding up the values of the cone volumes for the muscle in question. This calculation method was previously used by Heikkinen et al.[15]. Furthermore, Pons et al.[7] found that assessment of muscle volume by this method was the most valid and reliable method when studying the calf muscles.

Proposed CSA measurement methods

Five methods of single slice CSA measurement were investigated and evaluated. With 20 mm between every slice, the proposed practices were:

1. CSA measurement of all the calf muscles on the slice with the largest cumulative CSA of all muscle bellies.
2. The slice with the largest cumulative CSA was found by adding the measured CSA of the four muscle compartments and choosing the slice with the largest sum.

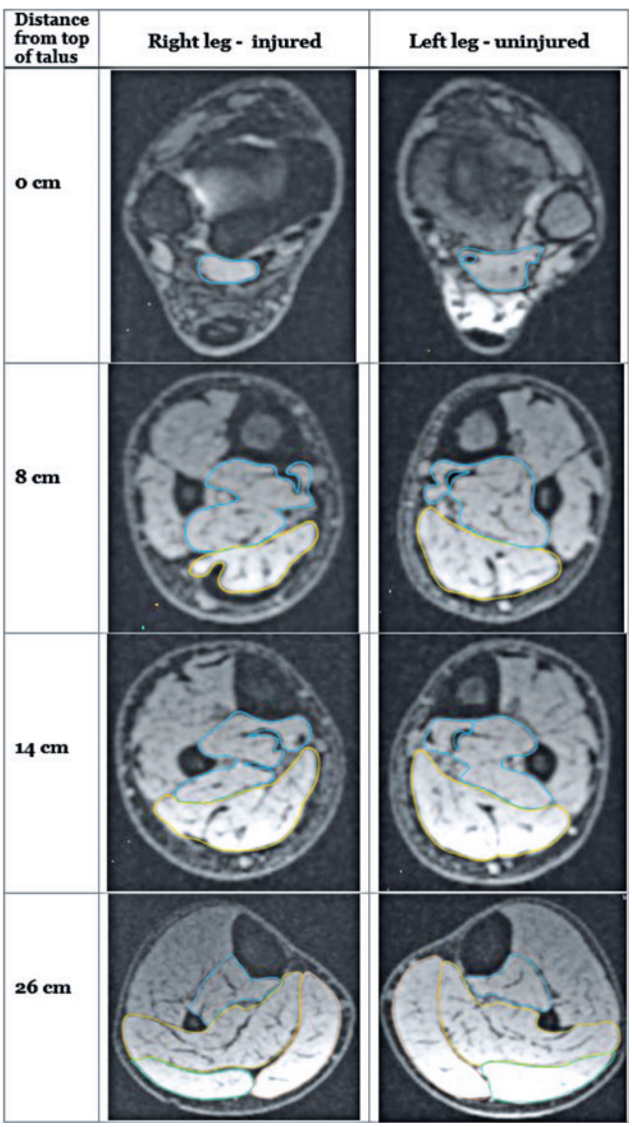

Figure 1. Axial slices from both legs of a random patient on four different distances from the top of the talus. The outlined regions define the muscle compartments of the deep flexor complex (blue), the soleus muscle (yellow), the medial head of the gastrocnemius muscle (orange), and the lateral head of gastrocnemius muscle (green).

3. CSA measurement of the individual calf muscles on the slices with the largest individual area.
4. The slice with the largest measured CSA of the individual muscles was identified and chosen.
5. CSA measurement of the calf muscles on a slice with a defined distance from the most cranial aspect of the talus bone.
6. The 13th slice, being 26 cm proximal to the distal reference slice, was chosen for every muscle.
7. CSA measurement of the calf muscles on the slice corresponding to 30% of the leg length.

   The leg length of every patient was measured, and the slice corresponding to 30% of the leg length was found.
8. CSA measurement of the deep flexors on four predefined distances from the most cranial aspect of the talus.

   The 3rd, 5th, 7th and 9th slice (being 6 cm, 10 cm, 14 cm, and 18 cm from the distal reference slide) were chosen for measurement of the deep flexors only.

Statistical analysis

With the volumetric measurements being the gold standard, LSI determined from the five methods of single slice CSA measurements were compared to LSI determined from the volumetric measurements. To evaluate the degree of variation between the volumetric measurement and the five models for single slice CSA measurement, a linear regression model was fitted for each model, and the R^2-values were determined as a measure of variance. After consultation with a statistician (TK) it was decided not to adjust for confounders, as each patient was its control and no relevant confounders were recognized.

Results

Sixty patients were enrolled, and 54 contributed to MRI data at one-year follow-up due to dropout (2 because ofwere pregnancypregnant, 1 because of long distance transport, and 3 with no reason). The distribution of the 54 participants was as follows: 45 males and 9 females, age (mean ± SD) 41.9 ± 9.2 years, height 178 ± 8 cm, and body mass index (BMI) 26.3 ± 3.6.

The results of the linear regression analyses are illustrated graphically in Figure 2, and the R^2-values are presented in Tables 1 and 2. The highest R^2-values for triceps surae (R^2 = 0.780), the soleus (R^2 = 0.612), and medial gastrocnemius (R^2 = 0.636) muscles were determined with method 3 (described in methods section). In terms of the lateral gastrocnemius, the strongest correlation (R^2 = 0.627) was obtained with method 2.

The deep flexors were examined further in method 5 where CSA was measured in shorter distances from the talus (Figure 3). The highest R^2-value (R^2 = 0.493) was obtained when measuring the CSA 14 cm above the talus.

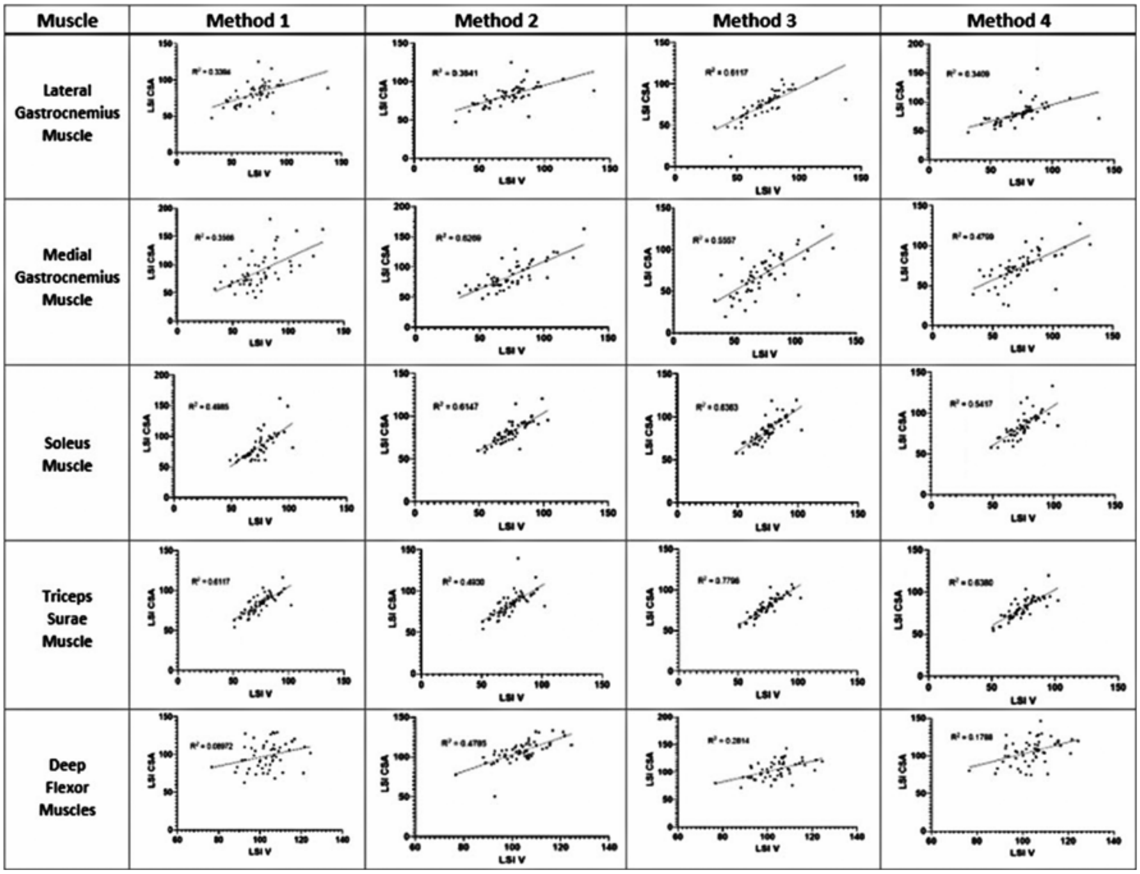

Figure 2. The graphs illustrate the correlations between the Limb Symmetry Index (LSI) derived from cross-sectional area (CSA) measurement on the y-axis and volumetric (V) measurement on the x-axis. Method 1: CSA measurement on the slice with the largest cumulative area of all muscle bellies. Method 2: CSA measurement on the slice with the largest area of the respective muscle. Method 3: CSA measurement 26 cm above the talus. Method 4: CSA measurement on the slice corresponding to 30% of the leg length.

Table 1. The R^2-values of the linear regression analyses for each muscle with the four methods.

R^2 - value	Method 1	Method 2	Method 3	Method 4
Medial gastrocnemius	0.339	0.384	0.612	0.341
Lateral gastrocnemius	0.357	0.627	0.556	0.480
Soleus	0.499	0.615	0.636	0.542
Triceps surae	0.612	0.493	0.780	0.638
Deep flexors	0.0897	0.479	0.281	0.179

Table 2. The R^2-value of the linear regression analyses for the deep flexors at four different distances from the talus.

R^2 - value	6 cm above talus	10 cm above talus	14 cm above talus	18 cm above talus
Deep flexors	0.214	0.437	0.493	0.323

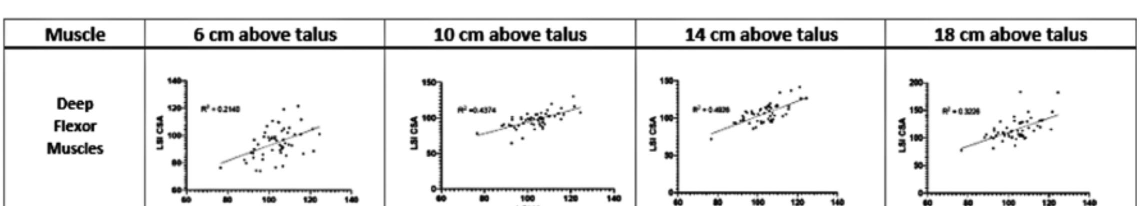

Figure 3. The graphs illustrate the correlations between the Limb Symmetry Index (LSI) derived from cross-sectional area measurement on the y-axis and LSI derived from volumetric measurement on the x-axis when investigating the deep flexors in 4 different distances from the talus.

Discussion

The most important finding of the study was that single slice CSA measurement, when examining the triceps surae as a muscle group, method 3 as described in section 2.5, correlated with volumetric measurement with an R^2-value above 0.7. However, single slice CSA measurement could not be used as a surrogate for volumetric measurement when investigating the individual muscle bellies as none of the proposed methods for single slice CSA measurements revealed R^2-values above 0.7.

When determining the CSA of the muscles 26 cm above the talus, method 3 yielded the strongest correlation amongst the four methods tested. Two factors may explain this finding. Firstly, the muscles investigated in all patients were consistently apparent to be 26 cm from the talus on the MRI. Secondly, the CSAs of the muscles are meticulously measured at the same distance from the talus on both the injured and the uninjured leg.

Assessing atrophy by CSA measurement of all the muscles on the slice with cumulative largest area, hence when applying method 1, yielded the weakest correlation. This method did not account for the variation in the individual muscles since not all triceps surae muscles were necessarily prominent on the slice with the cumulative largest area. Method 4, the CSA measurement of the muscles on the slice corresponding to 30% of the leg length, considers the difference in the individual patients' leg length. Therefore, it was surprising that the correlations in this method were inferior compared to method 3. We do not have a qualified physiological explanation for this finding. The distance of 30% was chosen as it showed the best correlations when compared with other distances.

Investigation of the deep flexors did not show a good correlation, but the best attainable correlations and R^2-values were achieved when the CSA measurement was performed within shorter distances from the talus. Contrary to the other muscles, the deep flexor complex is larger and more prominent on the CSAs with shorter distances to the talus, which might explain why the correlation was stronger closer to the ankle joint. This observation is supported by the finding that the highest R^2-value when investigating the correlation between CSA and volumetric measurement of the deep flexors was obtained when measuring the CSA 14 cm above talus (R^2 = 0.493) and is almost the same as the R^2-value obtained when measuring the CSA of the deep flexors on the slice where it had the largest area (R^2 = 0.479).

Quantification of muscle volume has been intensely studied over the past decades[7], but only four studies have investigated the muscle volume of the triceps surae evaluated by MRI[8-11]. A simple model assessing muscle volume from a product of the largest measured CSA and the length of the muscle has been validated in three studies. Albracht et al.[8] examined the method for individual muscle volumes within the triceps surae in thirteen healthy young athletes and found good validity (root mean squares 4%-7%) for all muscles in the triceps surae. Mersmann et al.[9] investigated 32 individuals (untrained individuals (n = 13), endurance (n = 9) and strength trained (n = 10) athletes). They found that the metrological quality was good when investigating the medial gastrocnemius (RMS 4.8%) and moderate when investigating the lateral gastrocnemius and soleus muscle (RMS 7.9%-8.3%)[7,9]. Finally, Vanmechelen et al.[10] investigated the measurement in healthy individuals and individuals with cerebral palsy and found a strong validity (R^2 between 0.955 and 0.988). The mentioned studies compared CSA and volumetric measurement on the same leg, with no prior injury or intervention.

One study investigated muscle change of the left lower limb in 20 subjects after 56 days of bed-rest by performing MRI at day 0 and day 56 and compared several methods of CSA measurement with slice-by-slice manual segmentation in detecting muscle change[11]. Five algorithms were tested; 1) the largest CSA, 2) the largest CSA and progressively incorporating the 13 slices immediately proximal and distal to it into an average and hereby evaluating the number of slices needed to attain the best correlation, 3) the same as algorithm two2 except that every second slice was taken distally and proximally, 4) the CSA at 30%, 50% and 80% of the muscle length, 5) the most proximal CSA of the muscle. To investigate the correlation a linear regression analysis was performed and it was found that algorithm 2 had the best correlations for lateral gastrocnemius (R^2 = 0.97, the average of the largest CSA and the CSA of the 7 slices proximal and distal to it), medial gastrocnemius (R^2 = 0.99, the average of the largest CSA and the CSA of the 2 slices proximal and distal to it) and soleus (R^2 = 0.98, the average of the largest CSA and the CSA of the 4 slices proximal and distal to it). Thus, a reduction of ~60% in the total number of manual CSA measurements was feasible in estimating changes in the muscle volume of the muscles in the triceps surae.

Our study is the first to investigate different methods of assessing muscle changes in the triceps surae after ATR. Considering the results from our study, applying CSA measurement on a single slice on MRI can be used as a surrogate for volumetric measurements when investigating atrophy of the triceps surae muscle as a whole, but we cannot recommend CSA measurement of the individual calf muscles based on a single MRI slice. If single slice CSA measurement based on LSI is to be utilized, the most precise estimations seem to be achieved by performing the CSA measurement of the muscles on slices where they are the most apparent and prominent.

Limitations

No test-retest was performed on the measurements; therefore, the reliability of the measurements is unknown. Furthermore, the measurement of atrophy was based on comparison with the uninjured leg, assuming that the legs had equal muscle volume before the injury. A recent study reported between-limb differences in the muscle volume of the individual muscles in the triceps surae were small and non-significant (mean symmetry index: 0.4% ± 4.1)[16]. Furthermore, the uninjured leg was affected during the rehabilitation. Some studies argue that the uninjured leg undergoes hypertrophy due to increased workload and others that the uninjured leg undergoes hypotrophy due to general inactivity in the rehabilitation period[17,18]. The optimal assessment of atrophy would be a comparison with preinjury values, but as this is not possible, we consider the chosen method the best alternative.

Conclusions

Cross-sectional area measurement on a single MRI slice 26 cm proximal to the talus can be used as a surrogate for volumetric measurements (R^2 0.78) when investigating atrophy of the triceps surae muscle group after Achilles tendon rupture. However, this approach is not suitable when investigating the individual parts of the muscleusing.

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Original Article

Low serum vitamin D levels are not associated with pseudoarthrosis and implant loosening in ankle arthrodesis: a retrospective cohort study

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Abstract

Objective: Analyze the relationship between hypovitaminosis D and pseudoarthrosis and implant loosening after ankle arthrodesis.

Methods: Retrospective and observational study using data extracted from the TriNetX international platform, including patients of both sexes, aged ≥ 18 years, undergoing tibiotarsal or tibiotalocalcaneal arthrodesis between 2016 and 2020, with at least one level of 25-hydroxyvitamin D in the perioperative period and one year of follow-up. Patients were divided into two groups: vitamin D deficiency (≤ 20 ng/ml) and no deficiency (> 20 ng/ml). Statistical analyses used logistic regression with propensity score matching, in addition to chi-square, Student's t, and Log-rank tests.

Results: Three hundred and six patients were selected for the study. After pairing, 72 patients were analyzed in each group. There was no statistically significant difference between the groups (adjusted OR = 0.878; 95% CI: 0.333-2.309; p = 0.7912). Similarly, there was no association between vitamin D deficiency and implant loosening/synthesis failure (adjusted OR = 1.017; 95% CI: 0.394-2.623; p = 0.9723).

Conclusion: The results indicate that vitamin D deficiency is not significantly associated with the risk of pseudoarthrosis or implant loosening in the short term. While supplementation may be beneficial, its clinical impact remains to be further investigated.

Level of evidence: II, Observational study.

Keywords: Pseudoarthrosis; Vitamin D deficiency; Arthrodesis; Ankle; Healing.

Introduction

The high prevalence of vitamin D deficiency is considered a concern worldwide, as it contributes to osteopenia, osteomalacia, and worsens osteoporosis[1]. Low vitamin D levels can dysregulate the homeostasis of the bone healing process in fractures and procedures such as ankle arthrodesis[2].

Vitamin D is synthesized in the skin under the influence of ultraviolet radiation and hydroxylated in the liver, forming calcidiol 25(OH)D, and later in the kidneys to its most biochemically active form: $1,25(OH)_2D_3$[3]. The active form binds to receptors in the intestine, kidney, parathyroid glands, and bone, regulating plasma calcium and phosphorus levels and subsequently bone mineralization and consolidation[4].

Recently, hypovitaminosis D has also been associated with poor clinical outcomes after orthopedic interventions, especially in spinal arthrodesis[5,6]. However, the relationship between hypovitaminosis D and clinical outcomes after arthrodesis procedures, including those performed on the foot and ankle, has not been fully investigated.

Study performed at the Hospital Alemão Oswaldo Cruz, São Paulo, Brazil.

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Total ankle arthroplasty has become a viable alternative for treating advanced osteoarthritis, especially in countries with broader access to this technology. However, ankle arthrodesis remains the most widely used approach, with consolidation rates greater than 90% with current techniques[7]. Despite these results, pseudarthrosis can occur in 5% to 40% of cases, leading to instability and possible implant loosening[8,9]. Factors associated with nonunion include the fracture type, avascular necrosis, infection, comorbidities, smoking, and alcohol abuse[10]. In addition, the procedure performed, the postoperative alignment achieved, and the type of stabilization employed are critical factors that can directly impact bone consolidation and implant stability[8,9].

Although previous studies have linked hypovitaminosis D to nonunion in orthopedic spine procedures, there is limited literature exploring the relationship between arthrodesis and serum vitamin D levels[11].

Therefore, the objective of this article is to analyze whether vitamin D deficit is associated with pseudoarthrosis and implant loosening in ankle arthrodesis procedures.

Methods

Data source

The data used in this study was collected on February 6, 2025, from the TriNetX Network, which provides access to electronic medical records, including diagnoses, procedures, medications, laboratory results, and genomic information, for approximately 130 million patients in 84 health organizations. This network comprises Healthcare Organizations, including academic centers, specialized medical centers, and hospitals. In Brazil, the data are centralized in the DataLab for Innovation, Research, and Education of Oswaldo Cruz German Hospital in São Paulo, which operates as a TriNetX hub institution in Brazil. The platform provides aggregated and de-identified data and statistical summaries from participating health organizations worldwide. This ensures that platform users do not have access to any protected health information or personal data. Access to the data is available through the TriNetX search network at https://live.trinetx.com.

Study design

This retrospective observational study was conducted using data from the TriNetX Research Network. Inclusion criteria were: (1) patients submitted to ankle arthrodesis (tibiotarsal or tibiotalocalcaneal) open or arthroscopic; (2) Age ≥ 18 years; (3) at least one measurement of 25(OH)D recorded in the perioperative period; and (4) patients with outpatient follow-up for at least one year. Patients with a history of malignancy, liver disease, acute infections, or septic shock were excluded from the analysis. The 25(OH)D values were categorized into two groups: cohort 1–vitamin D deficiency (≤ 20 ng/ml) and cohort 2–no deficiency (> 20 ng/ml)

Comorbidities were identified through the diagnostic codes of the International Classification of Diseases 10th revision (ICD-10)–(F17.2, I10, E08-E13, M19) and assessment of body mass index (BMI).

Outcomes evaluated

Incidence and prevalence of pseudoarthrosis and implant loosening/synthesis failure, within one year of follow-up of patients submitted to ankle arthrodesis. The outcomes were selected through the following ICD-10: M96.0 for pseudoarthrosis and T84.213, T84.21, and T84.22 for implant loosening/synthesis failure.

Ethical considerations

This retrospective study is exempt from Ethical approval. The revised data is a secondary analysis of existing data, does not involve intervention or interaction with humans, and is de-identified following the de-identification standard defined in Section § 164.514(a) of the Health Insurance Portability and Accountability Act (HIPAA). The process by which data is de-identified is attested through a formal determination by a qualified expert as defined in Section § 164.514(b)(1) of the HIPAA. This formal determination by a qualified expert was updated in December 2020.

Statistical analysis

Baseline characteristics of each group were compared using the chi-square test of independence for categorical variables and the paired Student's t-test for continuous variables. Demographic variations and comorbidities were extracted as covariates from electronic medical records, serving as potential confounding variables. Propensity score matching (1:1) was performed with logistic regression to control for age at the index date, sex, race, tobacco use, alcohol abuse, diabetes mellitus, BMI, and serum 25(OH)D levels. Propensity score was calculated using logistic regression implemented by the logistic regression function of the Scikit-learn package in Python version 3.7. After propensity score matching, measures of associations were used to calculate the odds ratio and risk difference, with 95% CI for the incidence of pseudarthrosis and implant loosening/synthesis failure. Kaplan-Meier analysis was performed to estimate cumulative probabilities of survival for each group one year from the index date using the Log-rank test. Statistical significance was established at $p < 0.05$ for all analyses.

Results

Baseline characteristics

Baseline characteristics of the cohort population are shown in Table 1. Patient selection (Figure 1) started with 3,767 patients, and after applying the exclusion criteria, the cohort included 306 patients aged ≥ 18 years. In cohort 1 (vitamin D ≤ 20 ng /ml), 92 patients with a mean age of 51.3 ± 13.7 were included. In cohort 2 (vitamin D cohort >20 ng/ml), 214 patients with a mean age of 58.7 ± 12.3 were included. Men were the majority in cohort 1, and women were the majority in cohort 2. The white race was more prevalent in both cohorts. Alcohol abuse (56.07%) and osteoarthritis (81.3%) were more present in cohort 2, while smoking (28.2%) was more reported in cohort 1. The percentage of BMI evaluated was similar, with a mean of 33.1 ± 8.46 in cohort 1 and 33.1 ± 7.41 in cohort 2. The mean 25(OH)D level was 14.6 ± 4.59 in cohort 1 and 36.2 ± 13.3 in cohort 2. Table 2 details the characteristics of cohort 1 after correspondence analysis, with 1:1 pairing.

Table 1. Baseline characteristics of the cohort before propensity score pairing.

ICD-10	Demographic data	Vitamin D ≤ 20 n = 92			Vitamin D > 20 n = 214			p-value
		Mean ± SD	n	% cohort	Mean ± SD	n	% cohort	
	Age	51.3 ± 13.7	92	100%	58.7 ± 12.3	214	100%	< 0.0001
	Men		51	55.4%		90	42%	< 0.0034
	Women		37	40.2%		112	52.3%	< 0.0518
	Race							
	White		58	63%		173	80.8%	< 0.0009
	Black		23	25%		17	79.4%	< 0.0001
	Unknow		10	10.87%		18	84.1%	< 0.494
	Comorbidities							
F17.2	Tobacco use		26	28.2%		40	18.6%	< 0.620
F10	Alcohol abuse		10	10.8%		12	56.07%	< 0.102
M19	Osteoarthritis		57	61.9%		174	81.3%	< 0.0003
	BMI	33.1 ± 8.46	74	80.4%	33.1 ± 7.41	179	83.6%	< 0.4962
	25(OH)D	14.6 ± 4.59	73	79.3%	36.2 ± 13.3	179	83.6%	< 0.0001

ICD-10: International Classification of Diseases 10th revision; SD: Standard deviation; BMI: Body mass index; 25(OH)D: 25-hydroxyvitamin D.

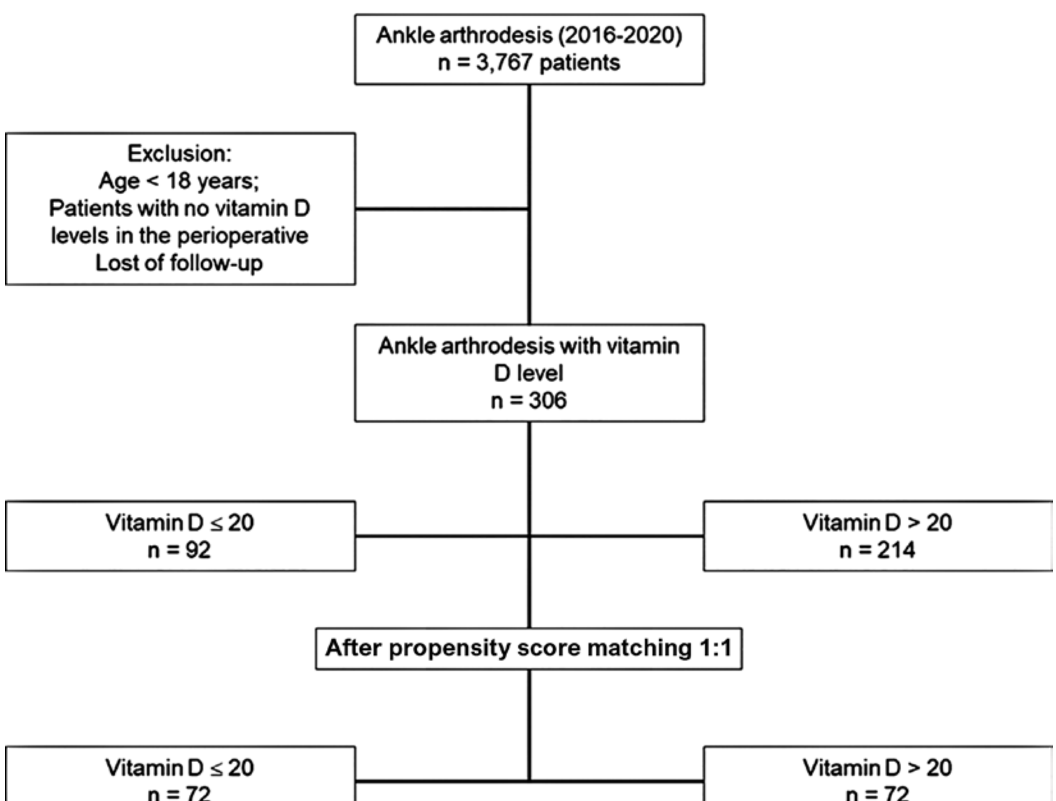

Figure 1. Algorithm for selecting patients for the study.

Table 2. Baseline characteristics of the cohort after propensity score matching 1:1.

ICD-10	Demographic data	Vitamin D ≤ 20 n = 92			Vitamin D > 20 n = 214			p-value
		Mean ± SD	n	% cohort	Mean ± SD	n	% cohort	
	Age	53.3 ± 12.9	72	100%	53.1 ± 12.1	72	100%	< 0.941
	Men		35	48.6%		36	50%	< 0.8676
	Women		35	48.6%		36	50%	< 0.8676
	Race							
	White		49	68%		48	66.6%	< 0.859
	Black		14	19.4%		13	18%	< 0.83
	Unknow		10	13.8%		10	13.8%	< 10
	Comorbidities							
F17.2	Tobacco use		16	22.2%		15	20.8%	< 0.83
F10	Alcohol abuse		10	13.8%		10	13.8%	< 10
M19	Osteoarthritis		47	65.2%		46	63.8%	< 0.86
	BMI	33.1 ± 8.82	55	76.3%	33.6 ± 7.97	53	73.6%	< 0.74
	25(OH)D	14.9 ± 4.69	59	81.9%	31.8 ± 11.1	60	83.3%	< 0.0001

ICD-10: International Classification of Diseases 10th revision; SD: Standard deviation; BMI: Body mass index; 25(OH)D: 25-hydroxyvitamin D.

The pairing process was responsible for pairing the baseline characteristics of the populations, such as age, sex, comorbidities, and vitamin D levels. After pairing, each cohort included 72 patients, and other similar data such as cohort 1 (men n = 35; woman n = 35); white race (cohort 1 (68%) vs. cohort 2 (66.6%)); smoking (cohort 1 (22.2%) vs. cohort 2 (20.8%)). The mean and standard deviation of serum 25(OH)D levels were the only characteristics that remained statistically significant after pairing the cohorts.

The incidence of pseudoarthrosis and implant loosening in cohort 1 was 21.1% and 10.86%, respectively. While the prevalence in the studied period was 27.7% and 10.86% (Table 3).

Outcomes

For the pseudarthrosis outcome, there was no significance regarding the difference in risk between groups: -1.919% (95% CI: -16.153% to 12.315%, p = 0.7912); The probability of pseudarthrosis between the cohorts was similar: Odds Ratio 0.878 (95% CI: 0.333 - 2.309) (Table 4). Regarding the analysis of pseudoarthrosis-free survival, the associated statistical analysis ($\chi^2 = 0.019$, p = 0.891), by the Log-rank test, indicated that there was no statistically significant difference between the survival curves (Figure 2).

For the implant loosening/synthesis failure outcome, there was no significance in relation to the difference in risk between the cohorts: 0.207% (95% CI: -11.463% to 11.877%), with p = 0.9723; The probability of pseudarthrosis between the cohorts was similar: Odds atio 1.017 (95% CI: 0.394 - 2.623) (Table 5). Regarding the analysis of pseudoarthrosis-free survival, the associated statistical analysis ($\chi^2 = 0.372$, p = 0.54), by the Log-rank test, indicated that there was no statistically significant difference between the survival curves (Figure 3).

Table 3. Table of incidence and prevalence of pseudoarthrosis and implant loosening in patients with vitamin D ≤ 20 ng/ml.

	Incidence	Prevalence
Pseudoarthrosis	21.1%	27.17%
Implant loosening	10.86%	10.86%

Table 4. Measures of association for pseudoarthrosis outcome before propensity score pairing.

		Cohort patients	Patients with results	Risk
1	Vitamin D ≤ 20 ng/ml	59	≤ 10*	16.94%
2	Vitamin D > 20 ng/ml	53	≤ 10*	18.86%

Risk difference	IC 95%	z	p	Risk ratio	IC 95%	Odds Ratio	IC 95%
-1.919%	(-16.15%; 12.31%)	- 0.265	0.7912	0.898	(0.406; 1.988)	0.878	(0.333; 2.309)

*13 patients in cohort 1 and 19 patients in cohort 2 were excluded from the results because they had outcomes outside the time frame. To protect patient privacy, numbers are rounded up to 10. This may affect the results, especially for small cohorts and infrequent outcomes.
CI: Confidence interval.

Discussion

In this retrospective cohort study using the international TriNetX database, reduced vitamin D levels (≤ 20 ng/mL) were observed but were not significantly associated with an increased risk of pseudarthrosis or implant loosening within one year. These findings challenge the widely accepted

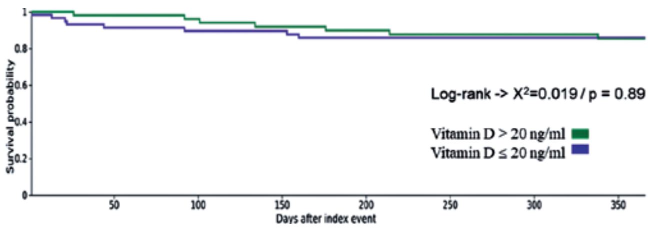

Figure 2. Kaplan-Meier survival curve for pseudoarthrosis outcome considering serum vitamin D level.

Table 5. Measures of association for implant loosening outcome after propensity score pairing.

		Cohort patients	Patients with results	Risk
1	Vitamin D ≤ 20 ng/ml	69	≤10*	14,49%
2	Vitamin D > 20 ng/ml	70	≤10*	14,28%

Risk difference	IC 95%	z	p	Risk ratio	IC 95%	Odds Ratio	IC 95%
-0.207%	(-11.46%; 11.87%)	0.035	0.9723	1.1014	(0.451; 2.283)	1.017	(0.394; 2.623)

*10 patients in cohort 1 and 10 patients in cohort 2 were excluded from the results because they had outcomes outside the time frame. To protect patient privacy, numbers are rounded up to 10. This may affect the results, especially for small cohorts and infrequent outcomes.
CI: Confidence interval.

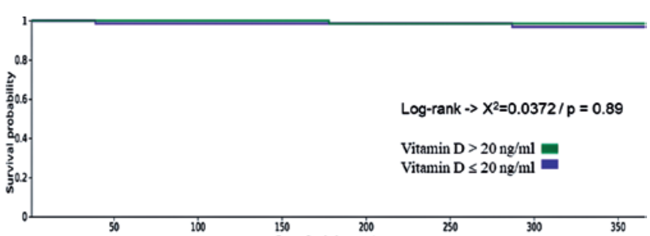

Figure 3. Kaplan-Meier survival curve for implant loosening outcome considering serum vitamin D level.

assumption that vitamin D deficiency alone is an essential factor in bone remodeling and, consequently, the stability of ankle arthrodesis implants[12].

The importance of this analysis lies in the need to differentiate purely metabolic and biochemical factors from biomechanical and structural factors[13], which can exert a greater influence on implant stability and bone healing in orthopedic surgeries[14].

In our study, the lack of a statistically significant association of the ratio and difference in risks of low 25(OH)D levels with pseudarthrosis differs from the systematic review by Christianson et al.[15] and the study by Gorter et al.[16], which correlate hypovitaminosis D with the difficulty of consolidation in orthopedic procedures. However, it agrees with the case-control by Moore et al.[17] and the observational cohort by Hendrickson et al.[18], in which there was no such correlation. In the literature, Igarashi et al.[19] reported a case of pediatric femoral fracture that progressed to pseudoarthrosis associated with vitamin D and K deficiency, suggesting that multiple metabolic factors may influence bone consolidation failure. However, this relationship has not been consistently reproduced in adult populations, in which factors such as biomechanical instability, inadequate axial load, and smoking have demonstrated a more direct impact on consolidation failure[20]. In fact, controversies are evident, and even more elaborate studies emphasize the need for new scientific evidence.

Almost an intrinsic relationship to pseudoarthrosis, the implant loosening is conditioned, although associated with several factors, to a biomechanical synthesis stability[21,22]. Some authors suggest that vitamin D deficiency could contribute to a chronic inflammatory environment, favoring periprosthetic osteolysis and, consequently, implant failure[23]. However, Maier et al.[24] demonstrated that reduced vitamin D levels were not an independent predictor of periprosthetic infection or implant loosening, suggesting that biomechanical and systemic factors may be more relevant to this process.

In contrast, studies such as that of Peersman et al.[25] hypothesize that elevated vitamin D levels could paradoxically increase bone resorption at the implant-bone interface due to local macrophage activation and periprosthetic inflammation. This mechanism could justify the absence of a linear relationship between hypovitaminosis D and implant failure, reinforcing that vitamin D supplementation does not always translate into direct clinical benefits.

Vitamin D supplementation has been widely recommended in orthopedic practice to optimize bone formation and prevent failures in reconstructive surgeries[26-28]. However, clinical evidence on its direct impact on pseudoarthrosis and implant failure is still limited and is further investigated in the context of dental implants[29]. Therefore, although there is evidence that severe vitamin D deficiency can affect bone formation, current data suggest that its replacement should be considered a complementary metabolic support, and not an isolated therapeutic strategy to prevent pseudoarthrosis or implant failure[30].

Thus, the evaluation of the orthopedic patient should be multifactorial, prioritizing bone quality, control of comorbidities, and surgical technique, without attributing exclusively to hypovitaminosis D the central role in implant failure.

Strengths of this study include the well-characterized cohort of patients with ankle arthrodesis and perioperative vitamin D levels. In addition to the comprehensive demographic and clinical data, the follow-up period. However, the study has several limitations. First, its observational design does not allow for the complete exclusion of residual or unmeasured confounding factors. In addition to the difficulty in establishing causal relationships or inferring direct causality. This issue can be addressed in future studies through randomization analyses. Second, searching for procedure codes and using ICD-10 codes can introduce inaccuracies, potentially leading to incorrect classification. Third, most TriNetX data is from structured electronic health records, often lacking detailed information about the selected endpoints. Fourth, the study population consists mostly of individuals from developed countries, which may limit the generalization of the findings to other populations with different demographic characteristics. Finally, data on multifactorial factors were limited. Despite these limitations, the study provides a valuable basis for future research on optimizing orthopedic surgeries regarding serum 25-(OH)D levels.

Conclusion

Vitamin D deficiency can influence bone formation, but there is no conclusive direct evidence that it increases the risk of pseudarthrosis or implant loosening in the short term. Preoperative supplementation may benefit patients with severe vitamin D deficiency, but its clinical impact still needs further investigation in randomized clinical trials.

Author' contributions: Each author contributed individually and significantly to the development of this article: ECSS *(https://orcid.org/0000-0001-5018-3923) Conceived and planned the activities that led to the study, wrote the article, participated in the review process, approved the final version; interpreted study results, participated in the review process; and participated in the review process; CDF *(https://orcid.org/0000-0002-6649-2066) Interpreted study results, participated in the review process; ROAF *(https://orcid.org/0009-0008-8466-8900) Interpreted study results, participated in the review process; SMFF *(https://orcid.org/0009-0001-4712-6159) Interpreted study results, participated in the review process; FDPR *(https://orcid.org/0009-0007-9143-1162) Interpreted study results, participated in the review process; DAS *(https://orcid.org/0009-0008-8395-8797) Interpreted study results, participated in the review process; MLSK *(https://orcid.org/0009-0009-9003-0863) Interpreted study results, participated in the review process; EAP *(https://orcid.org/000-001-60088671) Interpreted study results, participated in the review process; DLR *(https://orcid.org/0000-0003-0183-8641) Interpreted study results, participated in the review process. DRS* (https://orcid.org/0000-0002-7558-0359) Interpreted study results, participated in the review process. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Original Article

Early complications associated with the posterolateral surgical approach in posterior malleolar fractures

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Abstract

Objective: Determine the complication rates following the posterolateral surgical approach in posterior malleolar fractures and evaluate possible associations with comorbidities.

Method: Twenty-six adult cases of ankle fractures involving the posterior malleolus were treated with a posterolateral surgical approach. All cases were classified according to Lauge-Hansen, Haragushi, and Bartoníček classifications. Data analysis sought the relative frequency of complications, the statistical association between comorbidities, corticosteroid use, external fixators, previous skin lesions, and smoking.

Results: The incidence of postoperative complications was 38.4%. No statistically significant association was found between the development of postoperative complications and comorbidities, smoking, or corticosteroid use. In 50% of the cases, the fractures occurred during stage 3 supination external rotation, according to the Lauge-Hansen classification. Additionally, 3% of patients developed flexor hallucis longus adhesion, and 11% developed equinus deformity.

Conclusion: Overall complication rates after the posterolateral surgical approach in posterior malleolar fractures were 38.4%. No association was found between comorbidities or previous skin lesions and wound dehiscences. Additionally, 11% had postoperative Achilles tendon shortening.

Level of evidence: IV; Therapeutic studies; Case series.

Keywords: Ankle; Ankle fractures; Fracture fixation; Surgical wound dehiscence.

Introduction

Isolated lateral malleolar fracture accounts for 66% of ankle fractures; 25% present as bimalleolar fractures, and 7% as trimalleolar fractures[1-3]. The presence of a posterior malleolar fracture is related to a worse prognosis due to higher rates of subsequent osteoarthritis[4,5]. The posterolateral approach for internal fixation has been gaining popularity in recent years; however, there is a lack of studies detailing its complications and potential disadvantages.

Trimalleolar fractures are highly complex in terms of diagnosis, treatment planning, surgical management, and the risk of complications. The presence of a Volkmann's fragment, representing a posterior malleolar fracture, adds further complexity and increases the risk of postoperative complications[6,7]. In this context, identifying the most appropriate surgical approach, considering both the timing of intervention and potential postoperative complications, is essential[1].

Study performed at the Hospital Municipal Odilon Behrens, Belo Horizonte, MG, Brazil.

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Open reduction and internal fixation (ORIF) of the lateral and medial malleolus is routinely performed in ankle fractures; however, the management of posterior malleolar fractures remains controversial—particularly regarding the fragment size that requires fixation and the preferred surgical approach when intervention is indicated[3,4,6,8].

The posterolateral surgical approach provides effective access to anatomical reduction and stable fixation for posterior malleolar fractures, including large and small fragments, as well as non-displaced fragments, which can be fixed with ORIF or percutaneously with minimally invasive techniques[9,10]. This approach offers access to the fibula and tibia laterally, allowing fixation of the posterior fragment by the same incision using plate and/or screws, allowing better coverage of soft tissues when compared to the anteromedial approach[1,10-12]. Despite the advantages of the posterolateral surgical approach, early complications can affect the surgical wound healing[13,14]. It is important to note that one of the few limitations of this approach is the technical challenge it presents when the fracture involves anterior comminution of the joint.

With an individualized approach based on fracture morphology assessed through preoperative computed tomography (CT), the historically poor outcomes associated with trimalleolar ankle fractures could be significantly improved[15]. However, despite advancements in surgical indications and refinements in reduction and fixation techniques, controversy remains regarding the optimal individualized approach, and concerns have been raised about potential complications associated with the increased use of posterior approaches[16-19].

The most prevalent complications of the posterolateral approach are related to the surgical wound, occurring in approximately 11% of cases, according to the literature[19].

The objective of this study is to present clinical and radiographic data on complications following the posterolateral surgical approach in posterior malleolar fractures and evaluate possible associations with comorbidities.

Methods

The study was approved by the Institutional Review Board. Adult patients, of both sexes, submitted to surgery between 2019 and 2022 and agreed to participate in this study, were included. Patients diagnosed with isolated or associated posterior malleolar fractures through radiographs, surgically treated with the posterolateral surgical approach, were analyzed. Cases that presented inconsistencies in the medical record that led to the impossibility of data analysis were excluded.

A damage control approach was implemented when necessary, in accordance with the institution's protocol (e.g., open fractures, fracture-dislocations, high-energy trauma). All patients underwent preoperative ankle computed tomography (CT) and were submitted to definitive surgical treatment through the posterolateral approach. The criteria for surgical fixation included: displacement involving more than 30% of the articular surface, displacement greater than 1 mm, syndesmosis lesion, or impaction of the articular surface.

Data from medical records and imaging exams were evaluated retrospectively. Based on the trauma mechanism, the fractures were classified according to the Lauge-Hansen, Haraguchi, and Bartoníček classifications using CT. All classifications were performed by the same examiner, blinded to patient data. Additionally, data extracted from medical records included whether external fixation was used in the acute setting, skin condition at presentation, pre-existing comorbidities, smoking status, use of steroids and/or corticosteroids, and the occurrence of acute complications related to the posterolateral approach during posterior malleolus osteosynthesis.

Surgical technique

To perform the ankle posterolateral approach, the patient must be in prone position with a pad placed under the ipsilateral leg. A longitudinal posterolateral incision of approximately 8 cm is made between the Achilles tendon and the fibula. The sural nerve and the small saphenous vein are identified and carefully protected. The septum of the deep posterior compartment of the leg is then opened, and the flexor hallucis longus tendon is identified and retracted medially. This provides access to the posterior malleolus and is an anatomical reference to protect the neurovascular bundle.

All osteosyntheses of posterior malleolar fractures were performed using plates and screws under fluoroscopic guidance. After fracture reduction and fixation, wound closure was performed using Vicryl® 2.0 for the fascia and subcutaneous tissue, and Nylon® 3.0 for the skin.

For the postoperative period, patients were immobilized with a plaster cast for four weeks, followed by a removable boot and initiation of range of motion exercises from the fourth week, with no weight-bearing until the sixth week. Starting from week six, progressive weight-bearing was introduced alongside physiotherapy focused on improving range of motion, muscle strengthening, and gait training.

Statistical analysis

Statistical analysis was performed using SPSS software for Windows, version 26 (SPSS Inc., Chicago, Illinois, USA). The means, standard deviations, minimum, maximum, median and frequencies of the collected data were calculated. Significance analysis was conducted using the chi-square test, Mann-Whitney U test and Kruskal-Wallis test for non-parametric data. In addition, the odds ratio and the confidence interval were calculated. Multivariate analysis was employed to identify independent risk factors for complications. The significance level adopted was $p < 0.05$.

Results

Thirty-one patients were included in the study, but five did not meet the inclusion criteria due to incomplete data in the medical record, so 26 were analyzed. Among the cases included, 46.1% (12) were male and 53.8% (14) were female. The mean postoperative follow-up time was 12 weeks.

The most frequently injured mechanisms, according to Lauge-Hansen classification, were stage 3 supination external rotation in 50% (13) of cases, stage 4 pronation external rotation in 34.6% (9), and 15.4% (4) with stage 4 supination external rotation (Table 1).

At the time of initial evaluation, 69.2% (18) of patients presented with no skin lesions, and only 3.8% (1) involved an open fracture. Due to the need for damage control—such as in cases of open fractures, fracture-dislocations, or high-energy trauma—38.5% (10) of patients underwent initial external fixation: 1 for an open fracture, 3 for fracture-dislocations, and 6 for high-energy fractures. Definitive surgical treatment in these cases was performed after a median interval of 9.4 days.

Regarding medical history, 84.6% (22) of individuals were healthy, while 11.4% (4) had comorbidities such as anxiety, hypertension, dyslipidemia, depression, or hypothyroidism. Steroid use before the injury was reported in 3.8% (1) of cases. Additionally, 15.4% (4) had a history of smoking, and 3.8% (1) were chronic corticosteroid users.

The CT scans showed that of the 15 fractures classified as Haraguchi type 1, 10 were classified as Haraguchi type 2. Finally, one patient was classified as Haraguchi type 3.

The overall complication rate was 38.4%. Among these, 3% of cases developed shortening of the flexor hallucis longus, identified by difficulty in achieving full hallux extension, although the tendon showed no adhesions. Additionally, 11% of patients experienced Achilles tendon shortening, with maximum dorsiflexion limited to 90° on the Silfverskiöld test.

In total, 26.9% (7) of cases developed superficial wound edge necrosis that did not require additional surgical intervention. There was no statistically significant association between the presence of phlyctenae before surgery and the occurrence of postoperative complications (p = 0.289). No procedures were postponed due to the presence of phlyctenae. The median time for skin healing in patients with superficial skin lesions was 10 weeks.

There was no statistically significant association between the development of postoperative complications and the use of external fixators (p = 0.683), comorbidities (p = 0.625), smoking (p = 0.264), steroid use (p = 0.615), or chronic corticosteroid use (p = 0.385).

Regarding the frequencies observed based on the Haraguchi classification, 57.7% of cases were classified as type 1, 38.5% as type 2, and 3.8% as type 3 (Table 2).

According to the Bartoníček classification, no cases were classified as type 1; 50.0% were type 2, 19.2% were type 3, and 30.8% were type 4 (Table 3).

Table 1. Relative frequency of the trauma mechanism according to Lauge-Hansen classification

		Frequency	%	Valid %	Cumulative %
Stages	3 - SER	13	50.0	50.0	50.0
	4 - SER	4	15.4	15.4	65.4
	4 - PER	9	34.6	34.6	100.0
	Total	26	100.0	100.0	

SER: Supination external rotation; PER: Pronation external rotation.

Discussion

Trimalleolar fractures are highly complex due to factors such as the trauma mechanism, force vectors, diagnostic challenges, treatment planning, surgical intervention, and potential complications. The involvement of the posterior malleolus—characterized by the presence of the Volkmann fragment—further increases the complexity and the risk of postoperative complications associated with ankle fractures[20-22]. Given its relatively low frequency, accounting for approximately 7% of ankle fractures, there is a limited number of studies in the literature addressing complications specifically related to the posterolateral approach in its management[21-23]. It remains unclear whether these complications stem from the surgical approach itself or the inherent nature of the fracture, highlighting the need for comparative studies evaluating different surgical approaches for the same fracture type to provide clearer guidance.

In this context, the goal is to identify the most appropriate surgical approach for treating this type of fracture, considering the potential postoperative complications. This study evaluated the postoperative complications associated with posterior malleolus fractures treated through the posterolateral approach.

In this study, 26 posterior malleolus fractures were retrospectively evaluated following surgical treatment using

Table 2. Relative frequency of cases using Haraguchi classification

		Frequency	%	Valid %	Cumulative %
Types	1	15	57.7	57.7	57.7
	2	10	38.5	38.5	96.2
	3	1	3.8	3.8	100.0
	Total	26	100.0	100.0	

Table 3. Relative frequency of cases using Bartoníček classification

		Frequency	%	Valid %	Cumulative %
Types	2	13	50.0	50.0	50.0
	3	5	19.2	19.2	69.2
	4	8	30.8	30.8	100.0
	Total	26	100.0	100.0	

the posterolateral approach. The findings were consistent with the literature, showing a predominance of cases resulting from a supination external rotation mechanism. However, there was a slight predominance of female patients, contrasting with the current literature.

The overall complication rate in our study was 38.4%, slightly lower than that reported in the literature, which indicates a global incidence of skin complications of 44.2%[13].

At the time of initial care, 69.2% (18) of patients presented with no skin lesions, and only 3.8% (1) involved an open fracture. Due to the need for damage control, 38.5% (10) of the cases underwent initial external fixation. No statistically significant association was found between open fractures (3.8%) or external fixators (38.46%) and the development of postoperative complications (p = 0.683). Although the literature indicates that open fractures are a significant risk factor for infection[2,11-13,18,24], this discrepancy may be attributed to the sample size of our study.

Regarding skin complications, 26.9% (7) of cases developed superficial wound edge necrosis that did not require further surgical intervention. No statistically significant association was found between the presence of phlyctenae before surgery and the occurrence of postoperative complications (p = 0.289). Although the frequency of skin complications associated with the posterolateral approach is numerically relevant in several previously published studies, Abdelgawad et al.[6] argue that wound dehiscence following the posterolateral approach is generally less severe than that seen with anterior, lateral, or medial approaches, as implants are placed deeper and benefit from greater soft tissue coverage[8,14,22].

Regarding the data collected on the medical records, 84.61% (22) of individuals were healthy, while 11.39% (4) had comorbidities such as anxiety, hypertension, dyslipidemia, depression, or hypothyroidism. Steroid use before the injury was reported in 3.8% (1) of individuals, 15.38% (4) had a history of smoking, and 3.8% (1) were chronic corticosteroid users. No statistically significant association was found between the development of postoperative complications and the presence of comorbidities (p = 0.625), smoking (p = 0.264), steroid use (p = 0.615), or chronic corticosteroid use (p = 0.385), which is consistent with the findings of Tavares et al.[13].

Among the other complications observed, 3% of patients presented with shortening of the flexor hallucis longus, consistent with previous findings by Mertens et al.[25], who reported hallux flexion deficits in 30% of 50 patients treated via the posterolateral approach. No cases of sural nerve injury were identified in our sample. Additionally, 11% of patients developed Achilles tendon shortening—a complication not widely reported in the literature. This condition may result from temporary equinus immobilization or potentially be associated with the posterior surgical approach itself. It can often be reversed through an intensive postoperative physiotherapy program, and surgeons should address it proactively to prevent progression to a permanent equinus deformity.

Conclusion

Overall complication rates after the posterolateral surgical approach in posterior malleolar fractures were 38.4%. No association was found between comorbidities or previous skin lesions and wound dehiscences. Additionally, 11% had postoperative Achilles tendon shortening, and 3% of patients presented with shortening of the flexor hallucis longus. Further studies with larger sample sizes are needed to identify and prevent additional factors that may be associated with these complications.

Authors' contributions: Each author contributed individually and significantly to the development of this article: LAG *(https://orcid.org/0000-0003-0656-7270) Carried out the bibliographic review, organization of the collected data, interpreted the results of the study, formatting of the article, wrote the article, participated in the review process and approved the final version; YCA *(https://orcid.org/0009-0004-1275-5539) Interpreted the results of the study, statistical analysis, wrote the article, participated in the review process and approved the final version; GDH *(https://orcid.org/0000-0002-1830-450X) Performed the surgeries, data collection and approved the final version; ACO *(https://orcid.org/0000 0002 3477 830x) Interpreted the results of the study, participated in the review process and approved the final version; ACM *(https://orcid.org/0000 0003 2469 0424) Interpreted the results of the study, participated in the review process and approved the final version; SIK *(https://orcid.org/0000 0002 9079 6940) Conceived and planned the activities that led to the study, wrote the article, approved the final version. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Technical Tips

Subtle tarsometatarsal ligament injury in a professional ballerina: weight-bearing computed tomography technical tip

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Abstract

Early detection of Lisfranc instability is critical for improving clinical outcomes, but diagnosing subtle injury can be challenging. Magnetic Resonance imaging associated with weight-bearing computed tomography (WBCT) allows evaluation of such injuries in 3 dimensions (3D) under physiologic load. This WBCT technical tip aimed to assess the utility of the 3D measurements between medial cuneiform and the base of the second metatarsal (C1-M2), between the medial and intermediate cuneiforms (C1-C2), and between the first and second metatarsals (M1-M2) to diagnose subtle injury in isolated ligamentous Lisfranc injuries.

Level of evidence V, Therapeutic studies, Expert opinion.

Keywords: Wounds and injuries; Metatarsal bones; Weight-bearing; Computed tomography.

Introduction

The Lisfranc ligament stabilizes the foot's medial arch. The rupture of this structure can lead to the instability of the forefoot and midfoot[1]. Low-energy traumas usually cause ligament injuries and can be called subtle Lisfranc injuries[2-4].

While the weight-bearing radiograph is the traditional exam for diagnosing fractures and joint displacement, they have a higher chance of misdiagnosing ligament injuries. Among professional athletes, the rate of misdiagnosis is up to 41%, directly affecting the return to practice and the athlete's performance [5,6].

For this reason, computed tomographgy (CT) and magnetic resonance imaging (MRI) became standard care to evaluate the subtle Lisfranc injuries[6]. However, these exams are performed with the foot in a non-weight-bearing position when the joint is not in its most stressful position[6]. The cone beam CT allows it to do weight-bearing CT (WBCT) and to stress the foot joint in different positions[7-10].

This is a technical image tip for the decision-making of a professional ballerina for whom using the WBCT allowed us to define tarsometatarsal joint stability and decide between surgical and non-surgical treatment.

Case presentation

A 17-year-old female with 14 years of ballet experience was rehearsing. While in a jump, she felt and twisted her right foot in eversion. After this, she started to feel pain and difficulty walking. She went for an evaluation in the emergency room (ER).

In the first evaluation, the patient had swollen feet, midfoot pain, and pain in the foot mobilization. The initial radiograph

Study performed at the Hospital das Clínicas, Faculdade de Medicina, Universidade de São Paulo, São Paulo, SP, Brazil.

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was performed without weight-bearing and didn't reveal alteration. To complete the ER analysis, a CT scan indicated a possible Lisfranc ligament injury but without fracture or dislocation (Figure 1).

The patient was immobilized with a cam boot. She was released from the ER with a request for an MRI and to follow up with a foot and ankle specialist. The MRI showed a Lisfranc ligament injury without bone fracture, but it could not demonstrate if there were instabilities in the Lisfranc area (Figure 2).

The patient arrived for our evaluation with decreased pain and swelling. In our assessment, the patient presented without weight-bearing in the right lower limb and had a subtle positive piano key test. For these reasons, we used weight-bearing dynamic digital radiography and WBCT images to define the final treatment.

The weight-bearing radiograph, compared to the contralateral, did not show an increase in the Lisfranc space (Figure 3).

Technical image tip

The patient underwent a unique protocol with the WBCT.

Pre-treatment protocol

The first was a sitting-position bilateral WBCT scan, the second was a normal weight-bearing bilateral WBCT scan

Figure 1. Initial non-weight bearing radiograph and computer tomography did not show fracture and did not show significant increase of the Lisfranc area.

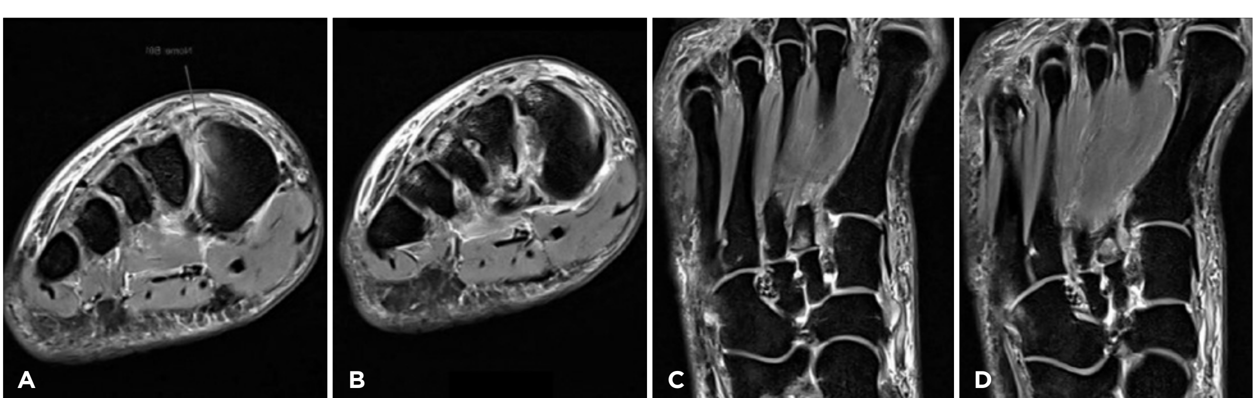

Figure 2. Initial magnetic resonance imaging of the edema and the Lisfranc ligament injury.

(Figure 4), the third was a demi-pointe weight-bearing bilateral WBCT scan to understand how the Lisfranc injury would affect the Lisfranc area since this is a position that the patient typically does in her ballet practice.

Figure 3. Weight-bearing dynamic digital radiography -without significant increase of Lisfranc the area comparing the right side to the left side.

Post-treatment protocol

The first was a sitting-position bilateral WBCT scan, the second was a normal weight-bearing bilateral WBCT scan (Figure 4), the third was a demi-pointe weight-bearing bilateral WBCT scan to understand how the Lisfranc injury would affect the Lisfranc area since this is a position that the patient typically does in her ballet practice, the forth was a pointe weight-bearing bilateral WBCT scan to understand how the Lisfranc healed injury affected midfoot bone relation and joint areas, since this is a final position that the ballerina typically does in her ballet performance.

The Lisfranc interosseous distance measurements were performed in the axial plane at the junction of the upper and middle third of the medial cuneiform, defined as 10 mm below its dorsal surface, as described by Bhimani et al[10]. These distances were between the medial cuneiform and the base of the second metatarsal (C1-M2), between the medial and intermediate cuneiforms (C1-C2), and between the first and second metatarsals (M1-M2) (Figures 5 and 6).

All measurements were performed using CubeVue software (Curvebeam, Pennsylvania, USA). Bhimani et al.[10] describes that C1-C2 and M1-M2 injury had normally a difference of 1.3 mm between foot, and 3.2 mm in the C1-M2. The differences C1-C2, C1-M2, and M1-M2 are described in Table 1.

Since the injury did not significantly increase the affected area, a non-surgical treatment was opted for the patient.

A protected weight-bearing with foam walker boot was allowed associated with insole midfoot arch support for eight weeks when the patient had no more symptoms, and after that, a full weight-bearing was allowed.

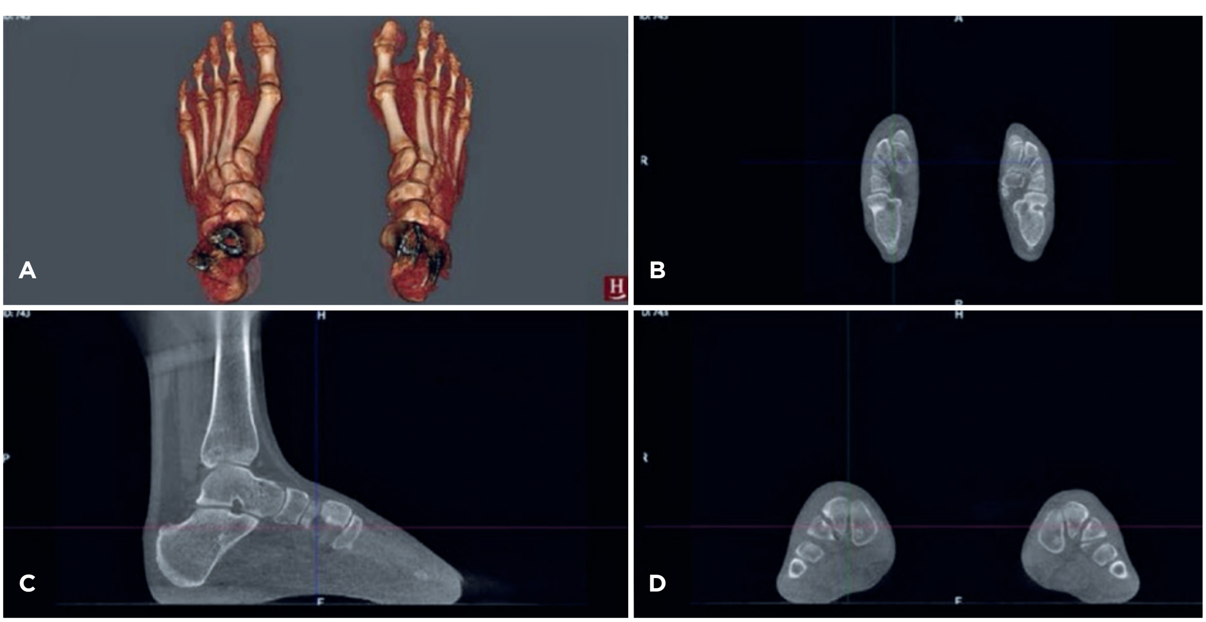

Figure 4. Normal weight-bearing computed tomography. A) 3- dimensional image of the bones; B) Axial image; C) Sagittal image; D) Coronal image.

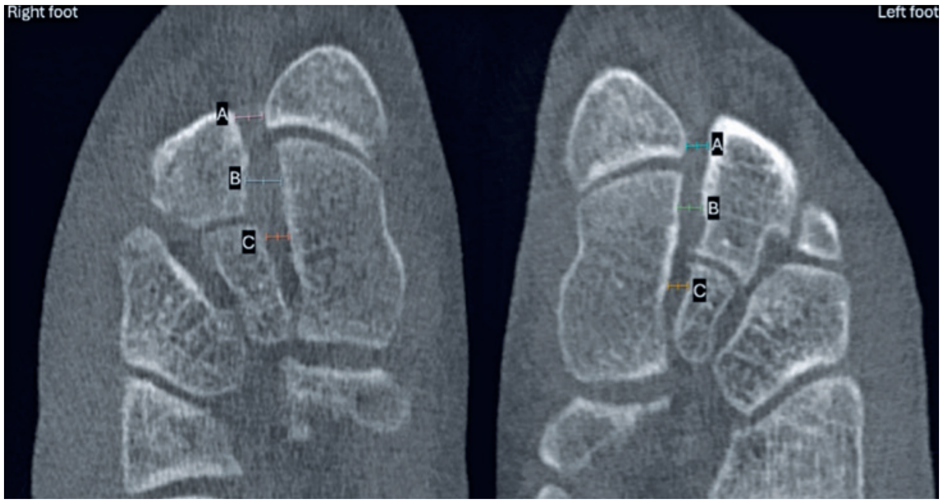

Figure 5. Weight-bearing computed tomography of a female patient with Lisfranc injury on the right foot. Axial plane of the feet. A) Distance between the first and second metatarsals (M1-M2). B) Distance between the medial cuneiform and the base of the second metatarsal (C1-M2). C) Distance between the medial and intermediate cuneiforms (C1-C2).

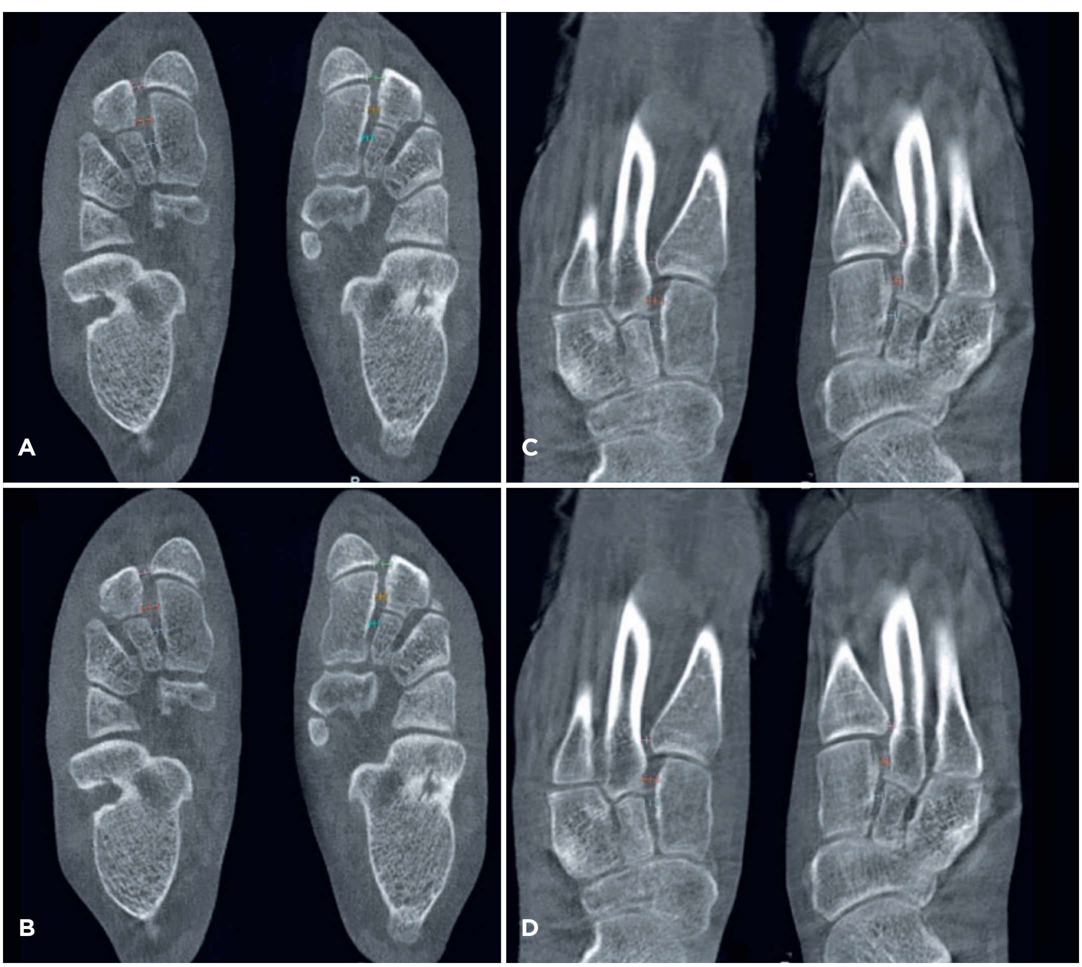

Figure 6. Weight-bearing computed tomography of a female patient with Lisfranc injury on the right foot. Axial plane of the feet. A) Sitting; B) Regular weight-bearing; C) Demi-pointe weight-bearing; and D) Pointe weight-bearing.

Table 1. Pre- and post-treatment weight-bearing computed tomography measurements C1-C2, C1-M2, M1-M2 in all protocol positions: sitting, regular weight-bearing, demi-pointe weight-bearing, pointe weight-bearing.

Pre-treatment	Sitting		Regular weight-bearing		Demi-pointe weight-bearing	
	Right	Lef;t	Right	Left	Right	Left
C1-C2 (mm)	3.7	3;1	3.3	3	2.6	2.1
C1-M2 (mm)	5.4	3;4	5.6	3.6	3.7	3.4
M1-M2 (mm)	3.4	3;1	4.2	3.3	2.8	2.4

Post-treatment	Sitting		Regular weight-bearing		Demi-pointe weight-bearing		Pointe weight-bearing	
	Right	Left	Right	Left	Right	Left	Right	Left
C1-C2 (mm)	3.4	3	3.6	3	2.6	2.1	2.8	2.1
C1-M2 (mm)	5.3	3;3	5.3	3.5	3.7	3.4	4.2	3.1
M1-M2 (mm)	3.2	3;1	3.8	3.4	2.8	2.4	1.9	1.4

The total return to sports was within 12 weeks; when the MRI was repeated, it showed ligament tissue healing at the Lisfranc topography (Figure 7).

At this mark, the WBCT using the same protocol adding pointe weight-bearing (Figure 8) was repeated, showing the return of the standard measurements.

Discussion

Diagnosing the pure ligamentous injury Lisfranc injury remains a complex challenge for orthopedic surgeons. While fracture-dislocations resulting from trauma are more straightforward, Lisfranc injury has a high rate of misdiagnosis and can define the return career of athletes[5,6].

The use of weight-bearing radiographs helps minimize misdiagnosis compared to the uninjured side; it can increase the measurable distance, making the diagnosis more evident[11,12].

However, the linear measurement can change depending on the foot's position, as it is based on a two-dimensional image[13-15]. Consequently, the patient's ability to bear weight on the injured side-limited by pain-can influence the measurement by changing how the patient steps and distributes weight on the foot.

The CT scan helps diagnose smaller fractures in the Lisfranc area[12,16,17]. It also helps determine whether a fracture involves articulation and how much displacement the fragment has[12]. Nonetheless, the exam is performed without weight-bearing and is effectiveineffective for diagnosing ligament injuries[13].

The MRI is an exam that can help diagnose the pure ligament injury and define the specific ligament involved[12,17]. However, it is also a non-weight-bearing exam, and the influence of this cannot be evaluated if it generates instability.

The WBCT can help evaluate the subtle Lisfranc injury[10,13]. It is faster than a normal CT scan and uses less radiation[8,13,18]. The scan can be performed with both feet simultaneously and in a weight-bearing position[13]. This allows for comparing

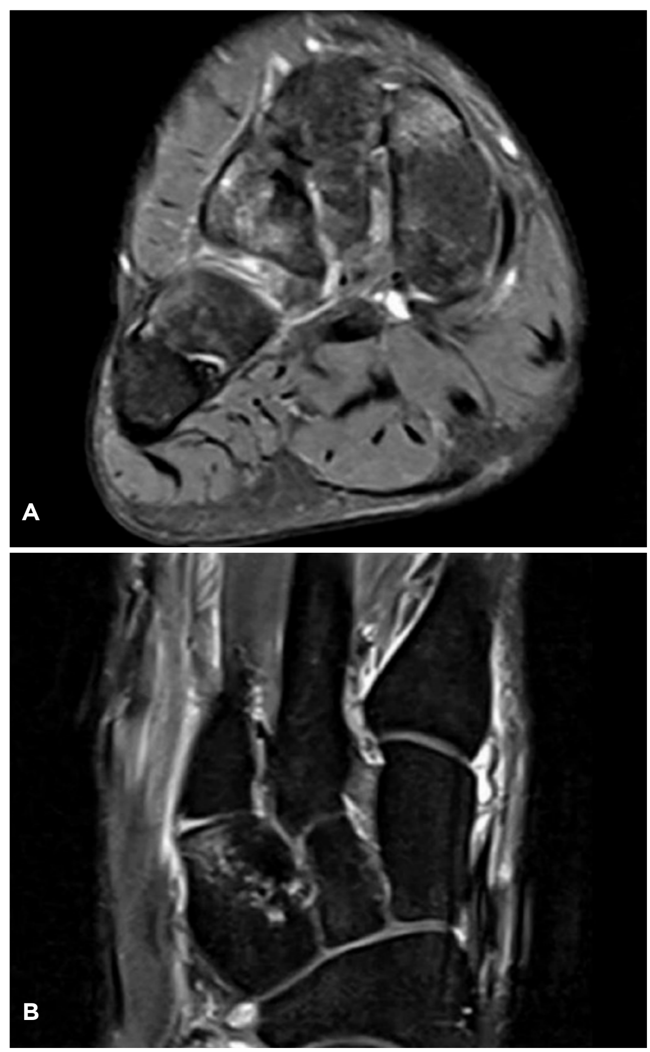

Figure 7. Magnetic resonance imaging after the treatment showing the ligament healing.

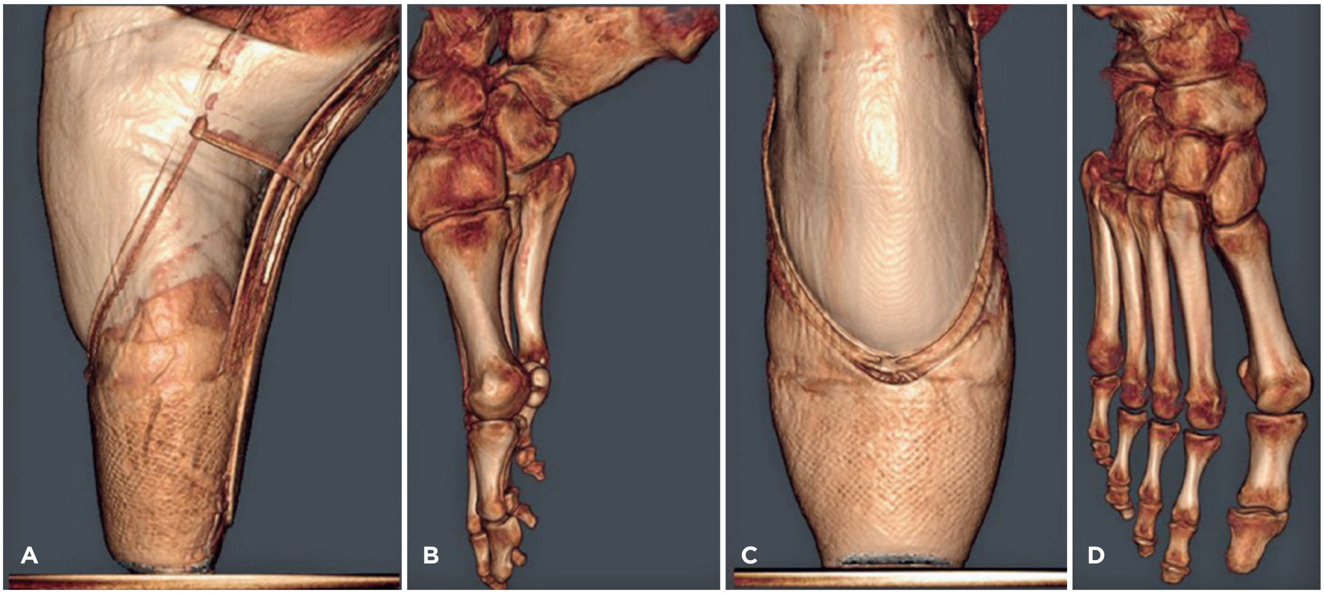

Figure 8. Pointe position weight-bearing computed tomography. A) 3- dimensional image of the foot sagittal view with pointe shoes; B) without pointe shoes; C) coronal view with pointe shoes; D) without pointe shoes.

the injured foot with the uninjured, and the weight-bearing generates a stressful position on the foot. Since the measurements are conducted in three-dimensional images, they have less influence on the feet's position on the floor[10,19]. Spirachi et al.[20] demonstrated that even in a partial weight-bearing (40 kg) WBCT can effectively diagnose the injury.

Bhimani et al.[10] describe different methods for assessing instability in the Lisfranc. They compare traditional unidimensional measurements with bi-dimensional and three-dimensional measurements. They found that the uni, bi-, and three-dimensional measurements accurately diagnose. For this reason, in our case, we chose the linear measurements similar to those used in weight-bearing radiographs.

The patient's measurements under full weight-bearing were similar in both feet, demonstrating the absence of instability in the region. To ensure that the injury would not affect her ballet practice, we performed a second scan in the full-pointe position. Even in the second position, the difference in area was similar in both feet. Since our patient did not demonstrate instability during this exam, a non-surgical approach was preferred.

To confirm the effectiveness of the non-surgical treatment, the patient underwent a new set of WBCT scans after 12 weeks of treatment. The latest measurements were similar to the previous ones, showing that the patient did not have instability, and in this case, a non-surgical treatment was appropriate. The importance of this comparison increases when the literature describes that a misdiagnosis of instability can lead to the end of an athlete's career.

Conclusion

Weight-bearing computed tomography may be a useful investigation to diagnose instability vs. stability of a pure tarsometatarsal ligament injury. When the patient does not have significant instability, non-surgical treatment with a foam walker boot combined with a midfoot support insole may be successful.

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Technical Tips

Endoscopic transfer of the flexor hallucis longus tendon: technical tip to harvest a long graft

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Abstract

The Achilles tendon (AT) is the toughest and most robust tendon in the human body. However, it is the most frequently injured. Several surgical techniques are described in the literature for treating chronic or complex injuries. Some of them use tendon transfers of the peroneus brevis, flexor digitorum longus and flexor hallucis longus (FHL). The FHL tendon transfer can be performed endoscopically (minimally invasive), a reliable method for treating AT ruptures. The objective of this study was to describe a technical tip to allow surgeons to harvest a longer tendon graft using a tendon stripper without the need for additional portals.

Level of Evidence V; Therapeutic Studies; Expert Opinion.

Keywords: Achilles tendon; Rupture; Tendon transfer; Endoscopy.

Introduction

The Achilles tendon (AT) is the toughest and most robust tendon in the human body. However, it is the most frequently injured, representing 20% of all tendon injuries in the human body[1]. The approximate incidence varies from 7 to 9 per 100,000 people, with most injuries suffered during sports[2]. These ruptures generally occur 2 to 6 cm proximal to the distal insertion of the tendon in an area of poor vascularity[3]. There is an important discussion about the treatment methods for these injuries. Nonoperative treatment and surgical sutures are the most used for acute injuries[4]. Several surgical techniques are described in the literature for treating chronic or complex injuries, such as V-Y tendon advancement of the gastrocnemius muscle or the technique described by Bosworth, which uses a central flap of the tendon itself to repair it[5]. Other authors have described surgical techniques using tendon transfers of the peroneus, flexor digitorum longus, and flexor hallucis longus (FHL)[6,7]. The FHL tendon transfer can be performed endoscopically (minimally invasive), a reliable method for treating AT ruptures and tendinopathy[8,9].

Despite the different surgical techniques, studies have shown no differences, in the medium term, between endoscopic treatment and open treatment concerning complication rates and functional scores[10]. Furthermore, some authors have reported difficulties in performing the arthroscopic sectioning of the FHL tendon as distally as possible to obtain a long enough tendon to allow its correct location and fixation to the calcaneus bone tunnel, which guarantees the stability of the construct, facilitating the healing of the transferred tendon[11].

The objective of this study is to describe a technical tip to allow surgeons to harvest a longer tendon graft using a tendon stripper without the need for additional portals.

Study performed at the Hospital Felício Rocho, Belo Horizonte, MG, Brazil.

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Surgical technique

The surgical procedure is performed under sedation combined with nerve block anesthesia. The patient is placed in the prone position on the operating table, with a tourniquet applied to the thigh and the leg positioned on a sterile pad while the foot hangs over the border of the table. A 4.0 arthroscope and 4.0 shaver are used.

Posterior endoscopy of the ankle is performed through the posterolateral and posteromedial portals, as described by van Dijk[12].

Initially, the posterolateral portal is used for visualization, and the posteromedial portal is used for instrumentation. The portals are alternated as needed to ensure optimal visualization throughout the procedure. After performing local debridement with a shaver, the FHL tendon is recognized (Figure 1). Before continuing with the procedure steps on the tendon visualized in the posteromedial region of the ankle, it is recommended to confirm that it is the FHL by flexing and extending the great toe. The FHL tendon has a path in the deeper layers, with the region close to the distal insertion being the only slightly superficial one. Its path can be divided into three segments, with segment one located posterior to the ankle[13]. The ankle was positioned in maximum flexion once the FHL tendon was recognized in segment one. An interlaced suture (VICRYL) is swiveled around the FHL to allow proximal traction. It is important to tug the swiveled suture around the tendon and make ankle and hallux plantar flexion to maximize the FHL tendon's length. Through the medial portal, the same one in which the suture was exteriorized, an open-head tendon stripper is introduced following the direction of the sutures tied in the FLH through the medial portal. Visualization of the stripper instrument position is through the lateral portal. Gentle and circular movements are performed with the instrument, following the same distal direction as the FHL and making sure that the tendon is completely embraced by the distal part of the stripper. The stripper reaches the roof of the FHL tunnel and does not hit the distal pulley. The tenotomy is performed while maintaining precise and circular movements up to the most distal portion of the tendon in the distal FHL tunnel. Through this movement, a longer tendon graft can be harvested (Figure 2).

The free proximal stub of the FHL was externalized through the medial portal, and a Krackow suture was applied with a non-absorbable thread, keeping it repaired outside the portal (Figure 3). Next, the calcaneal bone tunnel was performed by looking at radioscopy and endoscopy through the posterolateral portal. The diameter and length of the tendon are chosen according to the measurement of the distal tendon stub and following the biotenodesis instruments. In this case, the tunnel was drilled 30 mm long and 7.0 mm in diameter. The end of the FHL tendon was crossed through the tunnel and exteriorized on the plantar surface of the foot with a guide wire (Figure 4). The ankle was positioned between 5 to 10 degrees of flexion (physiological equinus position), and the adequate tension in the tendon was confirmed by pulling down the suture. After checking the satisfactory tensioning, by keeping the antigravity equinus, the FHL tendon was then fixed to the bone tunnel with an absorbable biotenodesis

Figure 1. (A) Posterior ankle endoscopic portals, camera, and shaver position (B) Posterior visualization of the flexor hallux longus after debridement.

screw (7/25 mm). Skin closure was preceded in the usual way, and the foot was immobilized with a plaster cast, keeping a position of 5 to 15 degrees of plantar flexion.

The postoperative rehabilitation began using a plaster cast, keeping the plantar flexion for 15 days. Then, a walking boot with wedges replaced the plaster cast and progressed

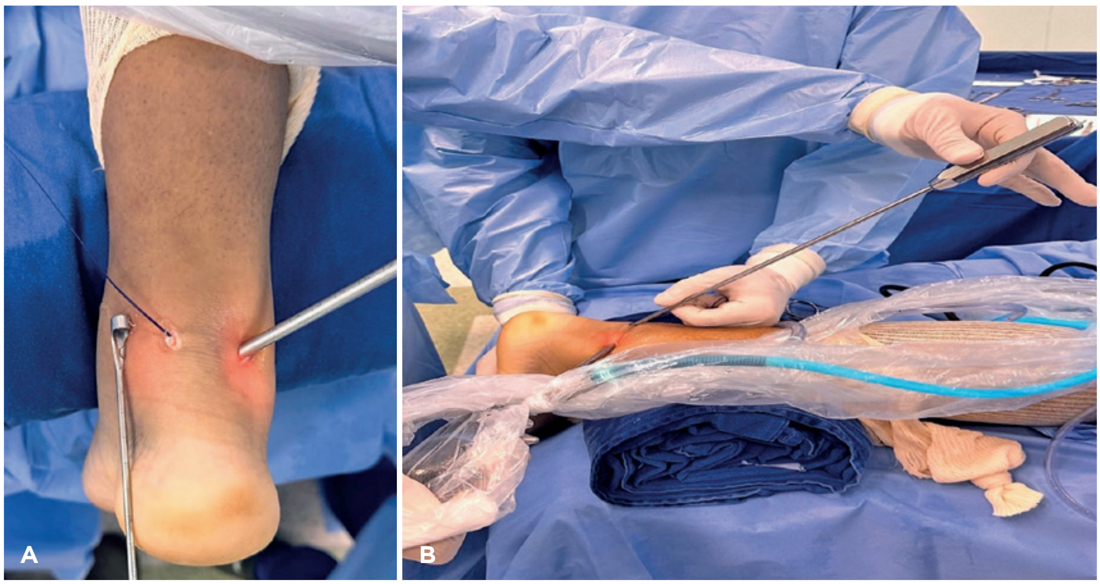

Figure 2. (A) Posterior view, camera in the lateral portal, wire outside the lateral portal holding the flexor hallux longus with a stripper being demonstrated (B) Striper positioned in the medial portal, with proximal to distal inclination, to follow the direction of the flexor hallux longus.

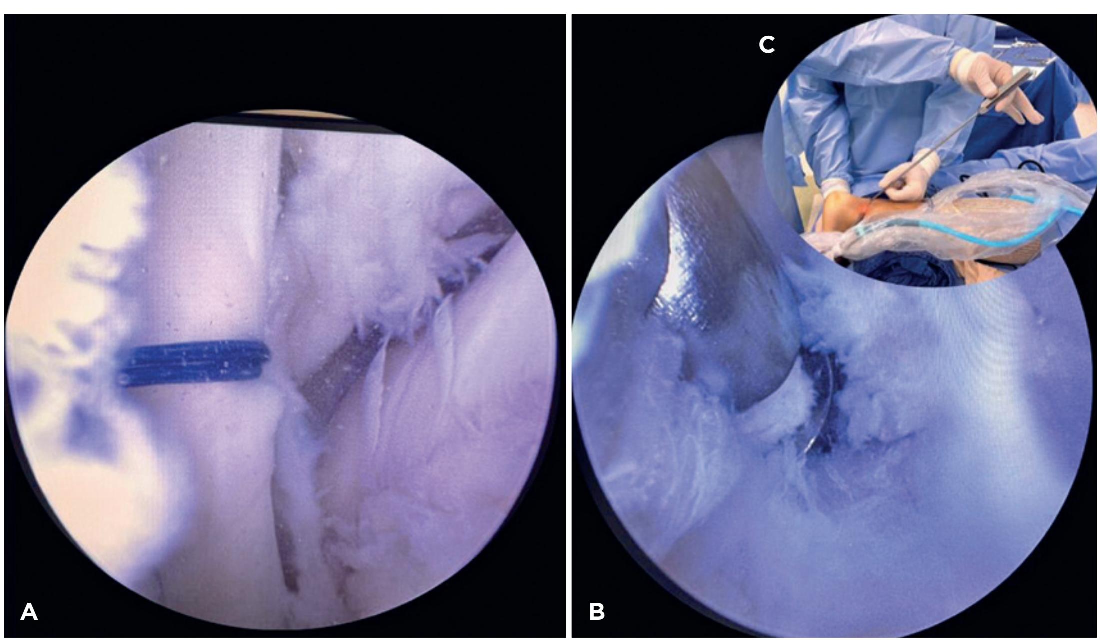

Figure 3. (A) Suture positioned in the flexor hallux longus to allow proximal traction (B) Stripper embracing the flexor hallux longus, applying distal rotational pressure to harvest the tendon (C) Proximal to distal position of the stripper, following the flexor hallux longus direction.

Figure 4. (A) Long length of the flexor hallux longus outside the medial portal (B) Equinus position of the ankle to introduce the interference screw (C) Endoscopic visualization of the interference screw fixing the flexor hallux longus in the calcaneus.

from the ankle flexion to a neutral position for 30 days, removing one wedge per week. The stitches were removed when the plaster cast was extracted. After using the boot, the patient was motivated to mobilize his ankles actively. An individualized physiotherapy was started after the removal of the walking boot.

Discussion

Open FHL tendon transfer is a consolidated technique for managing AT ruptures, providing excellent results; however, the endoscopic FHL transfer is just as efficient but with lower morbidity and better outcomes[11]. It combines advantages from a biological and biomechanical point of view while avoiding a more invasive procedure. Some important characteristics of the FHL make it a great tendon to replace the Achilles function in transfer cases. Initially, the FHL has a force vector in the same direction as the force vector exerted by the AT when it is functional. In addition, the most posterior region in which the tendon is positioned in relation to the calcaneus allows an increase in the strength and amplitude of the plantar flexion movement, respecting the basic principles of tendon transfers. The transferred FHL also provides physical support, helping to approximate the AT stubs[14]. The explained technique can actively interfere with the biomechanical aspect of the hindfoot by restoring the plantar flexion function. Furthermore, it can enhance the healing of the injured AT. The posterior reorientation of the FHL promotes an approximation of the AT with the muscular segment of the FHL, which has rich vascularization. The myotendinous junction of the FHL is close enough to the injured region of the AT to aid in its vascular supply. This proximity can also be increased by proximally releasing the FHL fascia. Moreover, it is also important to consider that the less invasive approach protects the paratendon and requires smaller skin incisions, which implies lower risks of wound infection, dehiscence, or difficulties in skin closure[1]. It is a safe and viable alternative to classic open procedures, promising highly satisfactory final results[15].

In the technique described above, a modification aimed to maintain all the biomechanical and biological advantages mentioned, in addition to seeking a longer tendon. A very useful instrument, also used to harvest the semitendinosus tendon, was used to perform a most distal tendon tenotomy[16]. The open-head stripper successfully performed the tenotomy of the FHL penetrating with no difficulty through the arthroscopic portal, allowing the removal of the longer tendon for subsequent quality fixation in the calcaneus. This technique was applied in more than ten cases. These were the last ones in which the endoscopic technique was used to treat AT ruptures. The main limitation of this technical tip is the impossibility of comparing the length of the tendon graft with the open procedure and other forms of endoscopic techniques. Further comparative studies need to be performed. In addition, the correct instrument must be available. An open-head tendon stripper is the appropriate tool. It is not possible to perform this technical tip with the closed stripper.

Conclusion

This technical tip can help remove a longer tendon in a less invasive procedure. However, a specific instrument is necessary. More comparative studies need to be performed.

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Case Report

Isolated traumatic dislocation of the posterior tibialis tendon: a case report

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Abstract

This case report describes a 65-year-old female patient with no previous comorbidities who suffered a traumatic dislocation of the posterior tibialis tendon during domestic activities. The initial diagnostic suspicion was a sprain; however, after suggestive physical examination and subsequent magnetic resonance imaging, dislocation of the posterior tibialis tendon was confirmed. The patient was submitted to tendon reduction, repair, and retinaculum reinforcement using tibial periosteal flaps. No complications occurred postoperatively, and after six months, the patient returned to her usual activities.

Level of Evidence IV, Therapeutic Study; Case Report.

Keywords: Ankle Injuries; Tendons; Ankle Joint.

Introduction

Traumatic dislocation of the posterior tibialis tendon is a rare and often underdiagnosed condition due to clinical similarity to ankle sprains. Since it was described by Martius in 1874[(1)], fewer than 50 cases have been reported in the literature worldwide[(2)]. Dislocation of this tendon usually results from traumas that combine extension and internal rotation of the ankle. Clinically, the patient presents with pain and edema in the medial region of the ankle—signs often mistaken with ligament injuries—making magnetic resonance imaging (MRI) the diagnostic tool of choice for a definitive diagnosis[(3,4)]. The literature, limited due to the extremely rare condition, recommends the surgical approach in most cases[(3,5,6)].

Case report

Clinical history

A 65-year-old female patient, retired, with no history of previous diseases, smoking or alcoholism, with regular practice of physical activities, such as dance and weight training. She had no history of trauma or injury to the affected limb.

During household activities, she tried to balance in a chair but slipped and rested his right foot on the ground, feeling a "snap" followed by intense pain in her right ankle. Due to the pain and instability in her limb, she could not keep walking.

Tests and diagnosis

In the emergency room, the initial radiograph of the ankle revealed no fractures or bone injuries. However, the physical examination demonstrated localized pain on palpation and during the excursion of the posterior tibialis tendon with passive ankle flexion-extension. Initially, the patient was treated with withdrawal of support and immobilization. An MRI was immediately requested, confirming the traumatic dislocation of the posterior tibialis tendon, which was displaced from its retromalleolar anatomical groove (Figure 1).

Study performed at the Clinical Hospital of the Federal University of Minas Gerais, Belo Horizonte, MG, Brazil.

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Given the diagnosis of traumatic dislocation, surgical treatment was chosen, considering the failure of conservative approaches in similar cases described in the literature. The patient underwent spinal anesthesia and was positioned in horizontal dorsal decubitus, with a pneumatic tourniquet at the thigh root to control bleeding.

The surgical access was performed with an incision of approximately 8 cm posteromedially, following the anatomical path of the posterior tibialis tendon (Figure 2).

A complete rupture of the posterior tibialis tendon retinaculum was observed during the procedure. The tendon was completely dislocated but showed no signs of rupture (Figure 3A-B) or changes in its sheath or bone avulsions.

Intraoperative assessment identified a shallow retromalleolar groove, prompting the decision to proceed with its deepening. For the sulcoplasty, a longitudinal osteotomy was performed at the edge of the groove, followed by curettage and removal of cancellous bone to deepen the bone-tendon contact surface without compromising its integrity.

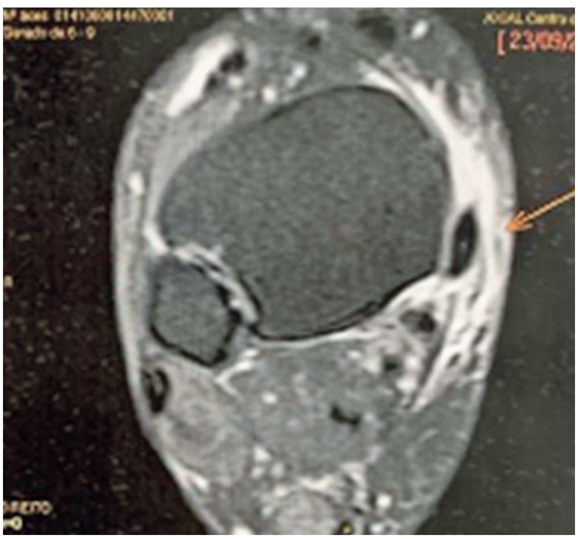

Figure 1. Ankle magnetic resonance imaging showing the posterior tibialis tendon located anteriorly to the retromalleolar groove.

Figure 2. The continuous line shows the planning of the surgical incision, while the dashed line shows the anomalous position of the dislocated posterior tibialis tendon.

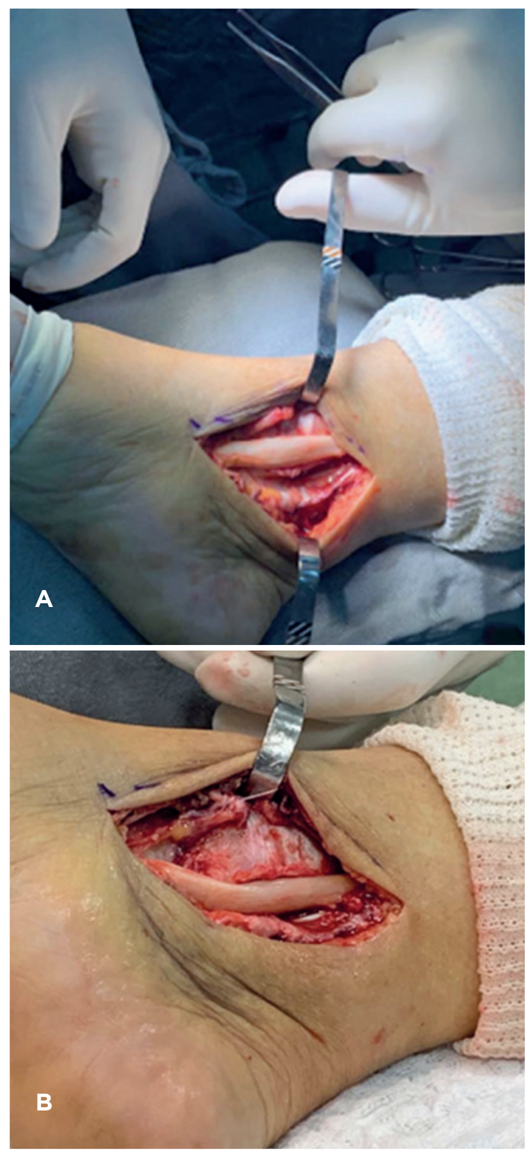

Figure 3. (A) Dislocated posterior tibialis tendon presenting anterior to the retromalleolar groove and under the medial malleolus. (B) Tendon in usual positioning after reduction.

After the tendon reduction in its groove, the retinaculum was repaired, providing good stabilization, as verified in the evaluation of the passive ankle movements. In addition, a retinaculum reinforcement was performed with tibial periosteal flaps to provide greater stability to the tendon (Figure 4).

Postoperative and outcome

The patient was periodically followed postoperatively. For the first six weeks, she remained immobilized with her ankle in a neutral position. From the eighth week, she started physiotherapy with active ankle flexion and extension exercises and progressive muscle strengthening.

She did not present significant pain or functional limitations in the three-month evaluation. At six months postoperatively, she reported a complete return to her usual activities, including physical exercise, with no signs of recurrence.

Discussion

Traumatic dislocation of the posterior tibialis tendon is a rare but potentially debilitating injury often confused with ankle sprains[7-9]. Early diagnosis is essential to avoid complications such as chronic ankle instability, progressive tendinopathy, formation of pseudoaneurysms in the medial region, progressive collapsing deformity, and persistent pain. These conditions can significantly compromise limb functionality and patient quality of life, reinforcing the importance of an accurate and timely diagnostic approach[7,8,10].

The posterior tibialis tendon originates from the posterior surface of the tibia and fibula, in addition to the interosseous membrane, and has multiple insertions, including the plantar face of the navicular, cuboid, cuneiform, and metatarsals[7]. It is contained in the flexors retinaculum, a structure located in the medial region of the ankle, along with the flexor digitorum longus tendon, the posterior tibial artery, the posterior tibial veins, the tibial nerve, and the flexor hallux longus tendon[7,10].

Figure 4. Tibial periosteal flaps were made and detached and then folded later to reinforce the retinaculum.

The main functions of the posterior tibialis tendon are plantar flexion of the ankle and inversion of the foot while also maintaining the medial longitudinal arch[9,11]. It has a sheath composed of two layers: one inner (synovial) and one outer (fibrous)[8,10]. The synovial layer is responsible for the production and secretion of synovial fluid, facilitating the sliding of the tendon and reducing its friction with adjacent structures. On the other hand, the fibrous layer is more resistant, provides mechanical protection, and maintains its positioning, especially during activities of high biomechanical demand[7,10].

Imaging tests are key in diagnosis and treatment planning[8]. Although MRI is widely recognized as the gold standard for evaluating soft tissues and confirming dislocation, dynamic ultrasound has become a complementary tool[7,8]. This method is particularly useful in assessing dynamic instabilities of the posterior tibialis tendon, allowing real-time observation of tendon movement and facilitating diagnosis in an emergency environment[10]. In addition, ultrasound is more affordable and cost-effective, making it a viable alternative in settings where MRI is not available[8,9].

Conservative treatment has high failure rates, and, therefore, surgery should be the treatment option, except in patients with low functional demand or who are unable to undergo the perioperative process[6].

Among the procedures described are the repair or reconstruction of the flexors retinaculum, the deepening of the groove of the posterior tibialis tendon, and the use of bone blocks[4,7,12].

In this study, the authors chose retinaculum reinforcement using tibial periosteal flaps. No previous descriptions were found in the literature about this technique modification. The objective of this change was to increase the strength of the construction and, consequently, provide greater stability for the posterior tibialis tendon in its groove.

No postoperative protocols are tested in the literature for treating posterior tibialis tendon dislocation[11]. In the case described, it was decided to immobilize in a neutral position for six weeks to protect the repaired retinaculum and avoid early stress during the initial healing phase[10,12].

Traumatic dislocation of the posterior tibialis tendon is rare and often underdiagnosed. Early diagnosis is essential to avoid complications such as chronic instability and tendinopathy. Magnetic resonance imaging is the gold standard for confirmation, but dynamic ultrasound offers a viable alternative in assessing instabilities.

Surgery should be the treatment option, evaluating the need to repair or retinaculum reconstruction, sulcoplasty, or bone blocks in each case. In this report, the authors described the treatment with sulcoplasty and retinacular reinforcement with tibial peristeal flaps, a technique unprecedented in the literature on the subject.

This case highlights the importance of establishing an early diagnosis to achieve a good functional recovery.

Authors' contributions: Each author contributed individually and significantly to the development of this article: GDH *(https://orcid.org/0000-0002-1830-450X) Conceived and planned the activities that led to the study, interpreted the results of the study, performed the surgeries, data collection, bibliographic review, survey of the medical records, clinical examination, approved the final version; AFB *(https://orcid.org/0000-0001-9751-9738) Interpreted the results of the study, participated in the review process, performed the surgeries, data collection, bibliographic review, survey of the medical records, clinical examination, approved the final version; LRFJ *(https://orcid.org/000-0002-3795-5471) Interpreted the results of the study, participated in the review process, performed the surgeries, data collection, bibliographic review, survey of the medical records, clinical examination, approved the final version; LASM *(https://orcid.org/0000-0002-1071-9946) Participated in the review process, bibliographic review, formatting of the article, approved the final version; PSOL *(https://orcid.org/0000-0001-6771-4524) 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, bibliographic review, survey of the medical records, clinical examination, 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

A case of chronic ankle osteomyelitis treated with bioactive glass and tibiocalcaneal fusion

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Abstract

Limb-salvage surgery in cases of chronic osteomyelitis poses significant challenges for orthopedic surgeons. This case report presents the first documented instance of a successful staged limb-salvage treatment for chronic ankle osteomyelitis, combining tibiocalcaneal fusion with bioactive glass (BAG). Bioactive glass S53P4 is a synthetic, biocompatible, osteoconductive bone substitute known for its bone-bonding capabilities, antibacterial and angiogenesis-promoting properties, which could be suitable for treating bone defects in infections. The subject of this case is a 68-year-old male with long-standing uncontrolled diabetes, who presented with a seven-day history of progressive left ankle arthralgia, purulent drainage in the medial aspect of the ankle, and low-grade fever. Imaging studies confirmed the diagnosis of chronic ankle osteomyelitis. The treatment involved a multidisciplinary approach including early antibiotic therapy, rigorous glycemic control, and staged surgical interventions using biomaterials. The first surgery was debridement and adequate irrigation, bone-void filling with antibiotic cemented spacer. Later targeted antibiotic therapy, after cultural examination, progressed to total contact casting and partial progressive weight-bearing. After 24 months of follow-up, with no clinical signs of infection, no gross alteration of gait pattern, and demonstrating complete bone healing, the patient was submitted to tibiocalcaneal fusion using bioactive glass. The BAG-S53P4 represents an interesting option as a bone substitute in chronic osteomyelitis with bone loss.

Level of evidence IV; Therapeutic study; Case report.

Keywords: Biocompatible materials; Osteomyelitis; Ankle; Bone substitutes.

Introduction

Chronic osteomyelitis often presents significant challenges in treatment, especially when it results in substantial bone loss. The standard approach usually involves surgical debridement to remove infected and necrotic tissue. In recent years, biomaterials have emerged as promising therapeutic options. The evolution of biomaterials can be categorized into three generations.

- **First generation**: These biomaterials were designed to be as bio-inert as possible, minimizing scar tissue formation at the interface with host tissues.
- **Second generation**: These biomaterials incorporated properties that actively stimulated tissue regeneration and repair, enhancing implant integration and stability.
- **Third generation:** These biomaterials were designed to stimulate tissue regeneration and repair through mechanisms such as gene activation.

Among the various bimaterials available, bioactive glass (BAG) has garnered attention, particularly due to its inventor, Lerry Hench, who developed it at the University of Florida in 1969, with a large use in craniomaxillofacial surgery in treating chronically infected bone.

Bioactive glass has unique properties that promote osteoconductivity and osteoinductivity, making it suitable for bone reparative procedures.

Specifically, BAG-S53P4 (composed of SiO_2, Na_2O, CaO, P_2O_5) has been shown to chemically bond with bone, promoting new bone formation. Its antibacterial properties

Study performed at the ASST FBF SACCO Luigi Sacco University Hospital, Milano, Italy.

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arise from localized increases in pH and osmotic pressure, resulting from the release of sodium and calcium ions along with phosphate salts. This environment inhibits bacterial adhesion and proliferation. Furthermore, BAG shows broad-spectrum bactericidal activity, and its ability to prevent biofilm formation has been well-documented. No induction of bacterial resistance to BAG-S53P4 has been reported to date. In this paper, we present our experience treating chronic ankle osteomyelitis in a patient with a history of an open distal tibia and fibula fracture. The case was managed by the same surgical team, at a single university center, in the North of Italy, during the COVID-19 pandemic lockdowns.

Case description

Preoperative management

A 68-year-old male patient sustained a displaced open fracture of the left distal tibia and fibula in July 1965 (AO Type 43-B3), following a high-energy motorcycle accident. He had no allergies. His medical history was significant for tobacco use (2 packs a day) and glycemic imbalance.

Upon admission, he was alert and oriented, with stable circulation and ventilation. Clinical examination of the left ankle revealed severe soft tissue contamination with a 3 cm laceration on the medial malleolus and a 2 cm laceration on the lateral malleolus, bone exposure, and significant deformity. Neurological and vascular assessments were normal. Wound cleaning, surgical debridement, and reduction with external fixation were performed. Antibiotic prophylaxis with 2 g Cefazolin intravenous and intramuscular tetanus toxoid was administered. However, by postoperative day seven, purulent drainage was observed from the wound sites, although no signs of infection were noted around the external fixator pins. The patient was diagnosed with an acute wound

Infection, prompting further debridement and tissue sampling, which identified *Staphylococcus aureus*. Targeted antibiotic therapy was administered for six weeks. The wounds evolved favorably, although a small ulceration area with a bleeding base persisted over the medial malleolar area and was slow to heal. Eight weeks later, the external fixator was removed, and definitive surgery with internal fixation was performed. Osteosynthesis material was removed after 12 months at the same center. He did well for several years with these procedures.

This patient came to our observation in June 2020 at the Emergency Department in a University reference center for infectious diseases, in Milan. The patient has a history of long-term uncontrolled glycemia and came to our observation for seven days of progressive left ankle arthralgia, present at weight-bearing, severe steppage, and local swelling. After three days of recovery, we noted the appearance of purulent drainage in the medial malleolar area and low-grade fever (between 37.5 and 38.5 c°). The patient was diagnosed with a chronic ankle osteomyelitis as shown by radiographs, computed tomography scans, and magnetic resonance imaging (Figure 1). A PET-CT scan confirmed the diagnosis of chronic osteomyelitis, and he was admitted to the Infectious Diseases Unit. A multidisciplinary team, including Infectious Disease specialists and orthopedic surgeons, evaluated the patient. Empirical antibiotic therapy was administered with 6 g Cefazolin intravenous, divided into three doses daily. Blood tests at the time of admission were: white blood cells 10.15 x 10^9/L, hemoglobin 130 gr/L, CRP 83.9 mg/L, glucose 130 mg/dL, fibrinogen 8.00 gr/L. The hemocultures for the search for aerobes and anaerobes were negative, as well as nasopharyngeal swabs tested for SARS-CoV-2 (RT-PCR), while the fistula swab resulted positive for Methicillin-sensitive *Staphylococcus aureus* (MSSA).

He was submitted to an initial surgical procedure in July 2020, which included debridement, multiple intraoperative culture tests, and the implantation of an antibiotic cement spacer, with resection of the medial and lateral malleolus. This created a large osseous rectangular deficit measuring approximately 3.75 x 2.5 cm^2. Intraoperative culture tests resulted positive for MSSA, Methicillin-resistant *Staphylococcus aureus* (MRSA), and *Escherichia coli*. Specific antibiotic therapy was administered with Piperacillin 4 g and Tazobactam 500 mg

Figure 1. Preoperative radiographs and computed tomography scans.

three doses daily and Teicoplanin 800 mg once daily. During the hospital stay the patient was submitted to a urinary tract infection by *Enterobacter aerogenes* and he was treated with Fosfomycin 3 g twice daily for one day and once daily for three days and subsequently with Sulfamethoxazole 800 mg and Trimethoprim 160 mg twice daily for five days and three doses daily for an additional five days. The patient remained hospitalized for 53 days.

A clinical and telephonic follow-up was performed six months postoperatively due to the COVID-19 lockdown.

In January 2021, after the second lockdown and after four months of antibiotic wash-out with a smoking cessation program and a diet for glycemic control he was admitted in the Orthopedics and Traumatology Unit and he was submitted to a second surgery of debridement, removal of antibiotic cemented spacer with a single transfibular approach, multiple intraoperative culture tests and tibiotalocalcaneal arthrodesis with a retrograde intramedullary nail and bioactive glass. Postoperative radiographs showed satisfactory results (Figure 2).

A non-weight-bearing cast was placed for four weeks, followed by a partial weight-bearing walker boot for an additional three weeks. Ten weeks postoperatively, radiological control was performed, and full weight-bearing was authorized. The follow-ups at 12, 24, 36, and 48 months the patient was pain free, he was walking without aids and no leg-length dysmetria and at 48 months follow-up he was submitted to surgery to remove a screw (Figure 3). The American Orthopaedic Foot and Ankle Society (AOFAS) ankle-hindfoot score, which is a health outcome score for patients after foot and ankle surgery, was used to assess the clinical outcome. This patient had a good outcome with a score equal to 86 at 48 months postoperatively, starting from a preoperative AOFAS score equal to 50 (poor outcome).

A stable union was achieved in radiological controls, and no wound-related complications were noticed.

Discussion

Our case report illustrates a successful application of isolated ankle joint fusion using BAG in the presence of extensive bone defects involving the tibia and talus.

This approach demonstrated an encouraging rate of osseous union and satisfactory functional outcomes. By integrating BAG with a meticulous surgical technique that included proper alignment and stabilization of the ankle joint, we achieved the dual goal of restoring ankle function and maintaining leg length. Various surgical techniques have been explored in the literature to restore bone stock and preserve leg length following ankle fusion.

These include: large structural iliac crest autografts (autografts are commonly employed due to their osteogenic potential, but they are limited by donor site morbidity); distal fibula autografts (Palisade technique) and femoral head

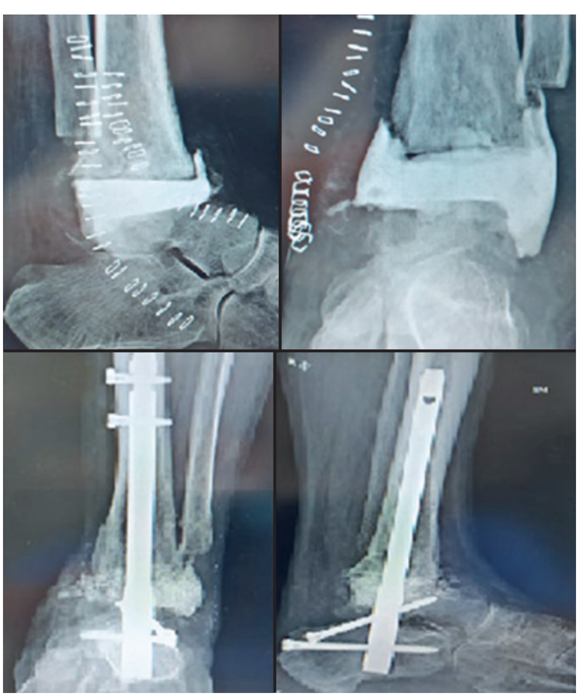

Figure 2. Postoperative radiographs.

Figure 3. Clinical examination at 48 months follow-up.

allografts (these grafts provide structural support–they often lack adequate vascularity, increasing the risk of nonunion and secondary collapse); bone cement (it serves as an effective temporary spacer); and trabecular metal interpositional spacers (it offers a porous scaffold for bone ingrowth)[1,2,3].

Additionally, allografts carry risks of disease transmission and immunogenic responses. Iliac crest grafting will result in a symptomatic donor site in < 48% of the patients, and bone cement as an artificial spacer is an inert foreign body that cannot integrate as well as a trabecular metal interpositional spacer[4]. Bone cement and trabecular metal spacers include difficulty in visualizing radiographic fusion and bone integration on plain radiograph or magnetic resonance imaging, as underlined by Frigg et al.[5] and Carlsson[6]. Trabecular metal, particularly tantalum, offers a porous scaffold for bone ingrowth but presents challenges in radiographic evaluation of fusion[5,6]. Ankle arthrodesis is a salvage procedure specifically aimed at preventing more proximal amputation. The goals of an ankle arthrodesis include realigning the ankle, alleviating pain by a solid union, and achieving a plantigrade foot. Multiple approaches have been described to achieve fusion, which remains a difficult goal with high nonunion rates.

In contrast, BAG has emerged as a superior alternative due to its dual function as a bone substitute and antimicrobial agent[7,8]. Its ability to chemically bond with bone facilitates osteogenesis, while its antibacterial properties, resulting from increased local pH and osmotic pressure, create an environment inhospitable to bacterial growth.

The use of a retrograde tibial nail with BAG as an osteoconductive scaffold for the treatment of chronic osteomyelitis is an excellent option to avoid recurrence of infection, leg-length dysmetria, with good clinical, functional, and radiological short-term results.

Specifically, research by De Giglio et al.[9] demonstrated that a significant decrease in the likelihood of requiring further antibiotic therapy in patients with diabetic foot infections treated with BAG, highlighting its role in improving osteomyelitis resolution rates.

Romanò et al.[10] reported an impressive 90% eradication rate with the use of BAG and confirmed the safety and efficacy of this biomaterial in a larger cohort, underscoring the safety and efficacy of this biomaterial in clinical applications. Despite the encouraging short-term results regarding clinical, functional, and radiological outcomes, the authors acknowledge the necessity for long-term studies to assess any potential delayed complications linked to BAG use in orthopedic procedures.

Conclusion

Ankle joint fusion using bioactive glass presents a viable and safe treatment option for chronic osteomyelitis, especially in cases with considerable bone defects.

Bioactive glass demonstrates excellent biocompatibility and serves as an osteoconductive scaffold with both osteogenic and osteoinductive properties, facilitating bone regeneration while mitigating infection risks. In our case, a multidisciplinary approach resulted in stable bone fusion without postoperative complications. We suggest BAG may be used as a structural scaffold for the second-step ankle arthrodesis in treating chronic osteomyelitis.

Authors' contributions: Each author contributed individually and significantly to the development of this article: MG *(https://orcid.org/0000-0002-6709-4406) Conceived and planned the activities that led to the study, wrote the paper, participated in the reviewing process; MML *(https://orcid.org/0000-0003-1416-0868) Wrote the paper, participated in the reviewing process; DB *(https://orcid.org/0000-0003-0925-5707) Conceived and planned the activities that led to the study and participated in the reviewing process; MS *(https://orcid.org/0009-0002-7428-6614) Conceived and planned the activities that led to the study and participated in the reviewing process; AM *(https://orcid.org/0000-0003-1791-6800) Conceived and planned the activities that led to the study and participated in the reviewing process. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Case Report

Streptococcus lutetiensis as a cause of calcaneal osteomyelitis, an unusual etiology: a case report

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Abstract

Streptococcus bovis is a well-known cause of endocarditis and joint infections, but is not commonly known as a cause of osteomyelitis. A patient with suspected calcaneus osteomyelitis was evaluated via magnetic resonance imaging and laboratory studies. Debridement was performed, and the result was chronic osteomyelitis caused by *Streptococcus bovis (lutetiensis)*, according to microbiological culture and pathology studies. A literature review of this microorganism as a cause of osteomyelitis has been conducted. Confirmation of a case of chronic osteomyelitis of the calcaneus caused by *Streptococcus lutetiensis* at approximately four months of evolution from the initial symptomatology was obtained, and patient was treated with surgery and antibiotics, resulting in resolution of the infection process. The American Orthopaedic Foot and Ankle Society (AOFAS) score improved from a preoperative value of 33 to 89 at six months after surgery. Osteomyelitis caused by *Streptococcus bovis* is a rare condition, and even less common in the *Streptococcus lutetiensis* subgroup.

Level of evidence IV; Therapeutic studies - investigating the results of treatment.

Keywords: Osteomyelitis; Streptococcus bovis; Calcaneus.

Introduction

Streptococcus bovis is a group of gram-positive bacteria strains associated with infections in animals and humans. The most frequently associated conditions are endocarditis, meningitis, septicemia, urinary and biliary tract infections, and, to a lesser extent, osteoarticular infections (including septic arthritis, spondylodiscitis, and osteomyelitis)[1].

This group of bacteria (*Streptococcus bovis/equinus*) has been reclassified based on phenotypic and genotypic differences as follows: a) *Streptococcus gallolyticus* subsp. *gallolyticus*, which was formerly known as *S. bovis* biotype I; b) *Streptococcus lutetiensis*, which was renamed from the previously known *S. infantarius* subsp. *coli,* which corresponded to biotype II; and finally, c) *Streptococcus gallolyticus* subsp. *pasteurianus*, which was previously known as biotype II/2.

The new classification is relevant because of the association between bacteremia/endocarditis and the presence of digestive tract cancer, which is subspecies-selective[2].

This microorganism can be identified in 10%-50% of patients with colon carcinoma[3].

In relation to osteomyelitis, the most frequent presentation is in the lumbosacral, cervical, dorsal, and iliac locations, in which symptoms may vary by an average of two months prior to diagnosis, with pain being the most frequently reported symptom[1].

Study performed at the Hospital Zambrano Hellion, Nuevo León, México.

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Case description

A healthy 65-year-old male with no known diseases frequently presented with oral cavity and gum infections, as confirmed by his sisters and father, which were reported as "aggressive" by patient. These infections caused the loss of most of the patient's teeth despite the treatments offered. Last dental extraction procedure was performed in August 2023, with good outcomes after the procedure.

In October 2023, patient went to his first contact physician complaining of swelling and pain in his left leg and foot, without previous trauma. Venous thrombosis was ruled out, and patient was referred to orthopedics. In his first evaluation at another institution, in November 2023, the main complaint was mild, diffuse pain in the left rearfoot during daily activities, self-medicated with non-steroidal anti-inflammatory drugs (NSAIDs). Patient's initial radiographs (Figures 1, 2, and 3) revealed mild subtalar and talonavicular arthrosis, marginal osteophytes, and increased volume of the soft tissues. The attending physician requested various laboratory studies and a magnetic resonance imaging (MRI) scan; however, patient preferred to be seen by another doctor and, initially, did not undergo the requested tests.

In January 2024, patient came to us for a second consultation, still presenting with swelling and pain in his left foot and ankle. On physical examination, patient experienced erythema and increased local temperature in the midfoot and ankle, increased pain in the medial ankle over the deltoid ligament and posterior tibial tendon, considerably increased soft tissue volume, positive fovea sign at the dorsum of midfoot and anterior aspect of the distal tibia, and diminished ankle range of motion due to pain. No bruises or scars were observed. Preoperative American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot score was 33.

Figure 1. Foot radiograph on weight-bearing, dorso-plantar view. Generalized decrease in bone density. Loss of definition of the margins of the talus, suggesting focal osteopenia. No evidence of fracture. Marginal osteophytes. Increased soft tissue volume.

Figure 2. Foot radiograph on oblique view. Generalized decrease in bone density. Loss of definition of the margins of the talus, suggesting focal osteopenia. No evidence of fracture. Marginal osteophytes. Increased soft tissue volume.

Figure 3. Foot radiograph on weight-bearing, lateral view. Generalized decrease in bone density. Loss of definition of the margins of the talus, suggesting focal osteopenia. No evidence of fracture. Marginal osteophytes. Increased soft tissue volume.

Blood tests and MRI scans were requested, and the following results were obtained: Hemoglobin: 7.94 mmol/L; Platelets: 466 x 10^9/L; Leukocytes: 7.77.7 x 10^9/L; Erythrocyte sedimentation rate: 50 mm/h; Ultra-sensitive C-reactive protein: 88.4 mg/L; Procalcitonin: 0.00006 mg/L; Glucose: 5.17 mmol/L; Albumin: 34 g/L; Lactate Dehydrogenase: 5.16 μkat/L.

At MRI, navicular bone showed increased signal intensity, more evident post-gadolinium, with erosion of its posterior margin, suggesting osteolysis. Talus bone exhibited increased signal intensity, more prominent post-gadolinium, with erosion of its anterior and inferior margins, suggesting osteolysis. Calcaneus bone displayed increased signal intensity, more evident post-gadolinium, with erosion of its superior margin at the sinus tarsi, suggesting osteolysis, as detected via T2-weighted MRI (Figures 4, 5, and 6).

Poorly defined inflammatory phlegmon adjacent to the superior and medial margins of the calcaneus, behind the long flexor tendon of the big toe, was identified, accompanied by marked inflammatory changes and edema of the soft tissues in the hindfoot, with thickening of the overlying skin and without evidence of gas. The presence of apparent abscesses in the calcaneus (Figures 7 and 8) and bone edema at talus, which is compatible with rearfoot osteomyelitis of apparent focus int he calcaneus, was further observed in comparative T1 and T2 images.

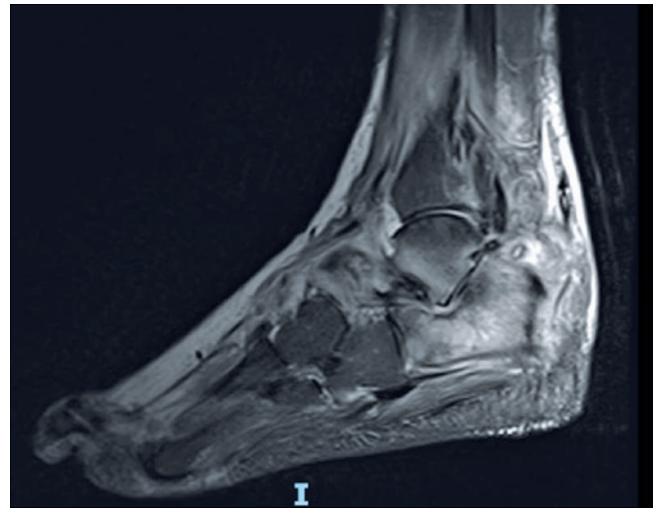

Figure 5. Mid-sagittal view magnetic resonance imaging scan. Navicular bone showing increased signal intensity, more evident post-gadolinium, with erosion of its posterior margin, suggesting osteolysis. Talus bone exhibiting increased signal intensity, more prominent post-gadolinium, with erosion of its anterior and inferior margins, suggesting osteolysis. Calcaneus bone displaying increased signal intensity, more evident post-gadolinium.

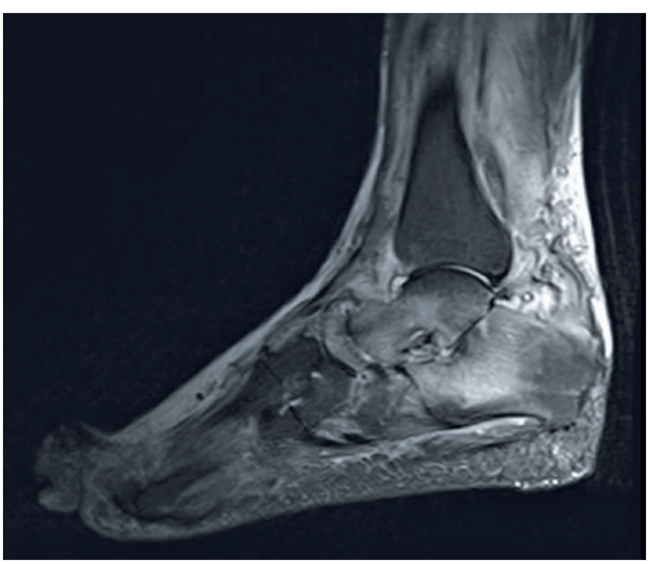

Figure 4. Mid-sagittal view magnetic resonance imaging scan. Navicular bone showing increased signal intensity, more evident post-gadolinium, with erosion of its posterior margin, suggesting osteolysis. Talus bone exhibiting increased signal intensity, more prominent post-gadolinium, with erosion of its anterior and inferior margins, suggesting osteolysis. Calcaneus bone displaying increased signal intensity, more evident post-gadolinium, with erosion of its superior margin at the sinus tarsi, suggesting osteolysis.

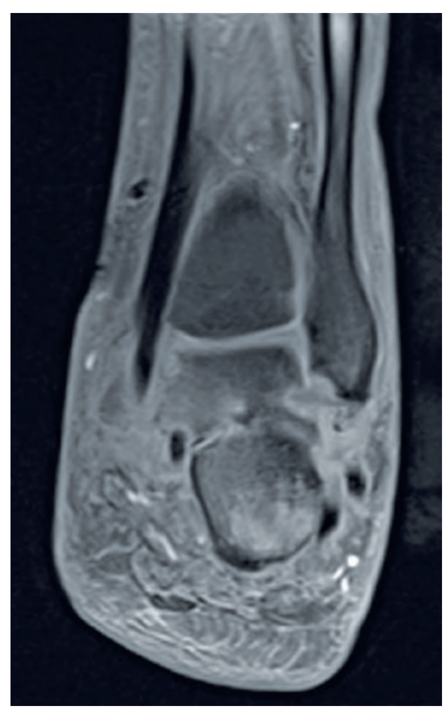

Figure 6. Coronal view magnetic resonance imaging scan. Talus bone exhibiting increased signal intensity, more prominent post-gadolinium, suggesting osteolysis. Calcaneus bone displaying increased signal intensity, more evident post-gadolinium, with erosion of its superior margin at the sinus tarsi, suggesting osteolysis.

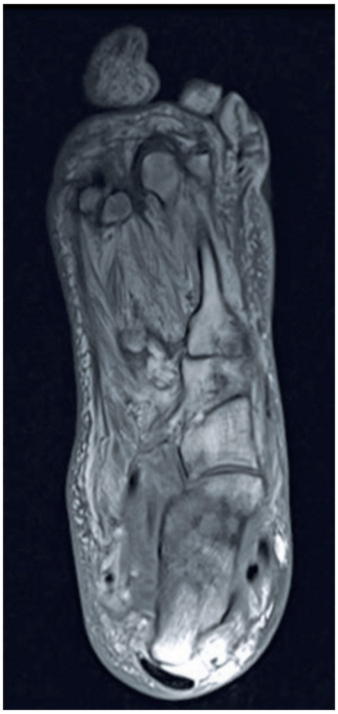

Figure 7. Axial view magnetic resonance imaging scan. Comparative T1 and T2 images, as well as the presence of apparent abscesses in the calcaneus.

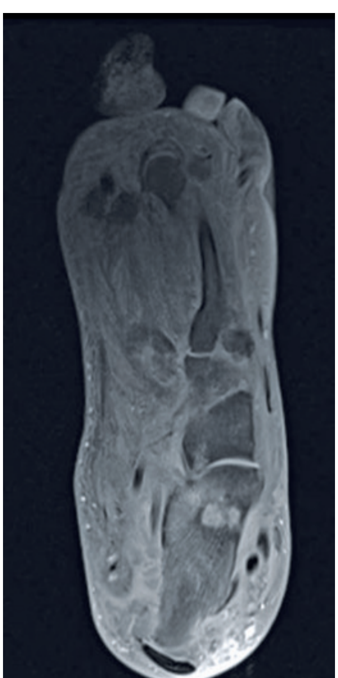

Figure 8. Axial view magnetic resonance imaging scan. Comparative T1 and T2 images, as well as the presence of apparent abscesses in the calcaneus.

Two days after hospital admission, patient was taken to the operating room for bone curettage and debridement of the calcaneus, along with biopsy and collection of bone tissue samples for culture through a direct lateral approach at the level of the anterior process of the calcaneus (sinus tarsi approach). A focus of osteomyelitis was identified due to changes in the consistency and coloration of the bone (necrotic bone and small purulent discharge) using fluoroscopic control. Curettage and irrigation of the area with sterile saline were performed. This was supplemented with a plantar-medial approach along the course of the posterior tibial tendon for exploration of the area due to local symptoms, revealing the posterior tibial tendon and flexor hallucis longus in good condition, with no signs of collections or infectious processes in this region. Irrigation was conducted and closure of this approach proceeded. The lateral approach was partially closed and prepared for placement of a negative pressure wound therapy (NPWT) system to temporarily manage the infection. Vacuum settings were adjusted at -125 mmHg (standard protocol).

Patient was initially treated with intravenous (IV) cefuroxime (750 mg every 8 hours) by an infectious disease specialist. After four days, the result of the calcaneal culture was obtained, and the growth of *Streptococcus lutetiensis* was reported. The antibiogram approved by the Clinical & Laboratory Standards Institute (CLSI) is shown in Table 1.

Given this result, antibiotic therapy was adjusted to IV ceftriaxone 1 g every 12 hours.

Seven days post-initial curettage, patient was re-evaluated in the operating room for removal of the NPWT system. Examination revealed improved local conditions of the calcaneus: improvement in the consistency of the surrounding cancellous bone around the initial infectious focus, presence of bone with active bleeding, absence of purulent material, and soft tissues demonstrating the presence of granulation tissue. A new irrigation procedure was performed, and a bone sample was obtained for control culture. The bone cavity resulting from curettage was then filled with calcium sulfate beads in combination with ceftriaxone powder. Finally, surgical incision was closed and covered with an ambulatory NPWT system.

Seven days after the first surgical procedure, result of the pathological biopsy was obtained, revealing presence of necrotic trabecular bone fragments and fibrous connective

Table 1. Antibiogram (calcaneal culture)

Antibiotic	MIC (mcg/ml)	Susceptibility
Amoxicillin	**≤ 0.25**	Susceptible
Clindamycin	**≤ 2**	Intermediate
Cefotaxime	**≤ 0.5**	Susceptible
Cefepime	> 2	Resistant
Penicillin	0.0625	Susceptible
Vancomicyn	**≤ 0.5**	Susceptible

MIC: Minimum inhibitory concentration.

tissue exhibiting dense inflammation and abscess formation. The inflammatory infiltrate consists of neutrophils, plasma cells, and lymphocytes. Negative for malignancy in relation to the presence of chronic osteomyelitis.

Given these advances and results, hospital discharge was decided. Management with amoxicillin 1 g orally every 8 hours was indicated, as well as daptomycin 400 mg orally every 24 hours for three weeks, initially; however, during follow-up with the infectious disease specialist, it was decided to extend antibiotic therapy to four weeks in total and that a new ultra-sensitive C-reactive protein test should be performed.

During the period of antibiotic management, patient reported considerable improvement in edema and pain and better function, without requiring assistance to ambulate or perform daily activities.

An ultra-sensitive C-reactive protein detection test was performed six weeks after antibiotic therapy was finished, and normal parameters were reported (3.2 mg/L).

As a complementary measure, a control colonoscopy was indicated considering the age and presence of the causal pathogen of osteomyelitis and its relationship with carcinomas of the digestive tract. No alterations or lesions suggestive of digestive tract cancer were reported.

The AOFAS score at six months was 89. Patient lost follow-up for living in another city.

Discussion

Osteoarticular infections caused by *Streptococcus bovis* are very infrequent, and the importance of their treatment is not only due to the identification of the specific causal microorganism but also due to its frequent association with digestive tract cancer (in up to 67% of cases)[4]. There is a high correlation between these subgroups and colon cancer or the presence of endocarditis[2], which is why the treatment does not focus only on osteomyelitis itself but also on the complete assessment of the patient. Sometimes, osteoarticular infections can be accompanied by infection at other sites without production of symptoms that would allow early management to be initiated.

With respect to the presentation of this group of pathogens, most musculoskeletal infections are related to spondylodiscitis, followed by joint infections either in native joints or with a history of prosthesis. Typically, this kind of infection is correlated with some type of cancer, most frequently in the digestive tract[2].

An interesting finding in our study is the identification of an association between biotype II of the *S. bovis* group (*S. lutetiensis*) and bacteremia with endocarditis in 18% of cases, as well as bacteremia with colon cancer in 17% of cases. Given this correlation, our case was performed through a multidisciplinary approach to rule out these conditions, which can often go undetected.

In summary, calcaneal osteomyelitis is exceedingly rare, particularly when caused by this microorganism. As few symptoms are presented, it leads to a chronic evolution of the infection; consequently, the treatment typically requires a combination of surgery and antibiotic therapy. An interesting aspect of this pathogen is its high sensitivity to antibiotics, as most cases can be treated with beta-lactams[5,6] and up to 50% of cases respond to management within less than six weeks, with a very low recurrence rate. However, once this microorganism is confirmed, it is essential to conduct additional complementary studies across various specialties due to its strong association with gastrointestinal cancer, where long-term follow-up is critical for achieving early-stage detection.

Authors' contributions: Each author contributed individually and significantly to the development of this article: OTVG *(https://orcid.org/0000-0002-7958-9676) Conceived and planned the activities that led to the study, perform the surgeries; LFHG *(https://orcid.org/0000-0001-9016-6167) Participated in the clinical examination, interpreted the results of the study, approved the final version; CFPV *(https://orcid.org/0009-0004-1706-2117) Participated in the review process, data collection; MIEC *(https://orcid.org/0009-0007-8786-300X) Participated in the review process, bibliographic review; AELR *(https://orcid.org/0000-0002-7234-2160) Interpreted the results of the study, participated in the review process, 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

Malignant glomus tumor of the foot: a case report

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Abstract

Glomus tumors are rare lesions, representing approximately 2% of all soft tissue tumors, and are most found in the subungual region of the extremities. We present a rare case of a malignant glomus tumor located in the plantar region of the foot in a young adult, which was treated surgically through wide local excision.

Level of Evidence V; Diagnostic Studies; Expert Opinion.

Keywords: Orthopedics; Glomus tumors; Diagnosis; Treatment.

Introduction

Glomus tumors (GTs) are mesenchymal neoplastic lesions derived from cells of the neuromioarterial glome or glomus body, which has, among its functions, thermal control in the extremities(1,2). They are extremely rare, representing approximately 2% of all soft tissue tumors, and are most found in the subungual region of the extremities(1,3). The typical presentation of GTs is a purple-red skin nodule, usually causing pain disproportionate to the size of the lesion(4). In addition, most TGs are benign and rarely demonstrate aggressive or malignant behavior and histological features(5). Malignant cases represent less than 1% of all GTs(6,7).

Glomus tumors associated with bones and joints are frequently overlooked(8). To date, just over 90 cases of bone and joint-associated GTs have been reported, likely due to the low incidence and high rate of misdiagnosis(4). In most cases, clinical symptoms and physical signs are not specific(8).

We present a rare case of a malignant glomus tumor located in the plantar region of the foot in a young adult, which was treated surgically through wide local excision.

Case report

This study was approved by the Institutional Review Board under the number 6,974,015.

This is a 26-year-old female patient who was referred to the service due to a mass on the plantar surface of the left foot, with severe pain—rated 8 out of 10 on the visual analog scale—and difficulty walking for about six years. There was no history of previous trauma or incidents. Pain intensified when walking, standing, and upon manual pressure applied to the mass region. The patient noticed progressive but slow growth in this period.

On clinical examination, no deformities were observed in the weight-bearing feet; however, the patient presented with an antalgic gait pattern. Inspection revealed a visible mass in the plantar region of the midfoot and forefoot. Palpation of the mass elicited increased pain. The range of motion was within physiological limits across all examined segments. Neurological and vascular assessments of the affected limb showed no abnormalities.

A contrast-enhanced nuclear magnetic resonance (NMR) scan was performed, revealing an expansive lesion involving both the superficial and deep soft tissues of the left forefoot and, to a lesser extent, the midfoot. The lesion primarily affected the flexor muscles of the third, fourth, and fifth toes. It exhibited a hyperintense signal on T2-weighted images and an isointense signal on T1, with contrast enhancement (Figures 1-6). The lesion measured 7.5 cm × 2.7 cm × 3.5 cm.

An incisional biopsy was performed, confirming the diagnosis of a malignant GT. The patient subsequently underwent

Study performed at the Hospital das Clínicas Samuel Libânio, Pouso Alegre, MG, Brazil.

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a wide-margin resection of the neoplastic lesion (Figures 7 and 8). In the late postoperative period, wound dehiscence occurred but was successfully managed with second-intention healing (Figure 9). The patient experienced complete resolution of pain, regained normal gait function, and remains under follow-up with local and systemic staging, showing no signs of local recurrence or systemic disease.

Discussion

Glomus tumor, a rare condition arising from the abnormal proliferation of glomus body cells, is notable for its uncommon presentation and the diagnostic challenges it poses[4]. Early identification is crucial, as these tumors—although typically benign—can cause significant pain and negatively affect the patient's quality of life. In rare instances, they may exhibit malignant potential, with reported metastasis rates reaching up to 38%[6,7]. Treatment usually involves surgical excision, prioritizing the preservation of surrounding anatomical structures[3].

Doutrelon et al.[9] reported the case of a patient with a suprapatellar GT that caused painful claudication. The diagnosis was confirmed through magnetic resonance imaging (MRI), and the patient was submitted to complete surgical tumor resection, resulting in full resolution of the pain. According to the authors, GT located in atypical regions can easily go unnoticed, increasing the risk of delayed or incorrect diagnosis. However, their symptoms can often be effectively resolved with a simple surgical excision.

Kato et al.[10] reported the case of a 32-year-old male patient who presented with severe dorsal pain. Despite normal findings in initial clinical examinations, the MRI revealed an arthrosynovial cyst. Following surgical resection and histopathological analysis, the lesion was confirmed. The authors emphasized that an accurate differential diagnosis—supported by imaging tools such as ultrasound and MRI—is essential for determining the appropriate therapeutic approach. They noted that surgical resection is often the treatment of choice and highlighted the importance of a thorough and careful clinical evaluation to ensure effective management of GT cases.

In the largest published series of extradigital GT cases from the Mayo Clinic over the past 20 years, only 3.5% of tumors were in the foot. This rarity is attributed to the low concentration of glomus bodies in the feet, including in subungual regions. In the foot, common differential diagnoses include Morton's neuroma, hallucis flexor longus tendonitis, plexiform neurofibroma, plantar fibromatosis, and subungual exostoses[11].

A case series published in 2015 analyzed the characteristics of 11 GTs diagnosed in the feet at a North American center. The mean age at diagnosis was 45.4 years, ranging from 28 to 60 years, with a distribution of three men and eight women.

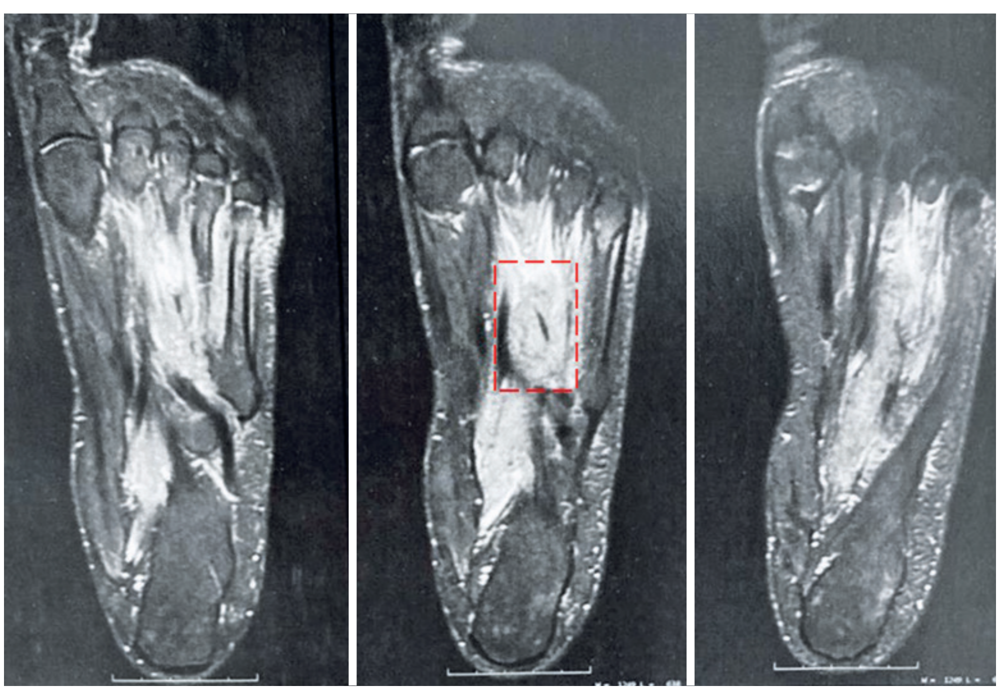

Figure 1. Expansive lesion of superficial and deep soft tissues of the left forefoot and, to a lesser extent, the midfoot, compromising mainly the flexor muscle of the third, fourth, and fifth toes, with hyperintense signal on T2-weighted and an isointense signal on T1 with contrast enhancement.

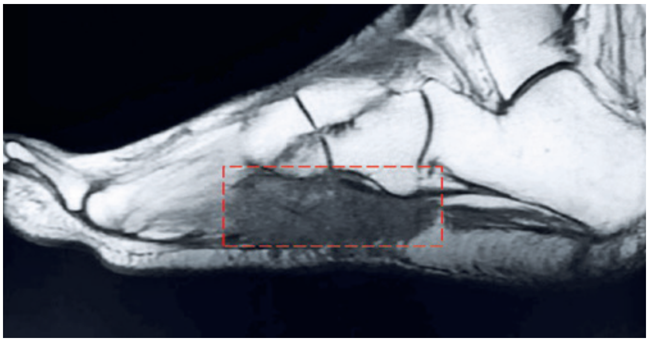

Figure 2. Image in the sagittal section of the foot showing mass (marking in the figure) in hyperintense signal on T1.

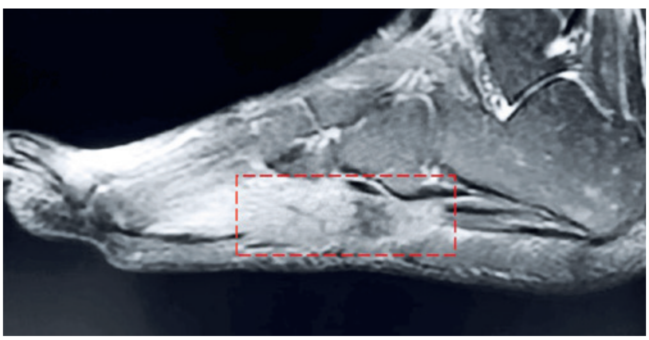

Figure 3. Image in the sagittal section of the foot showing mass (marking in the figure) in isointense signal on T2.

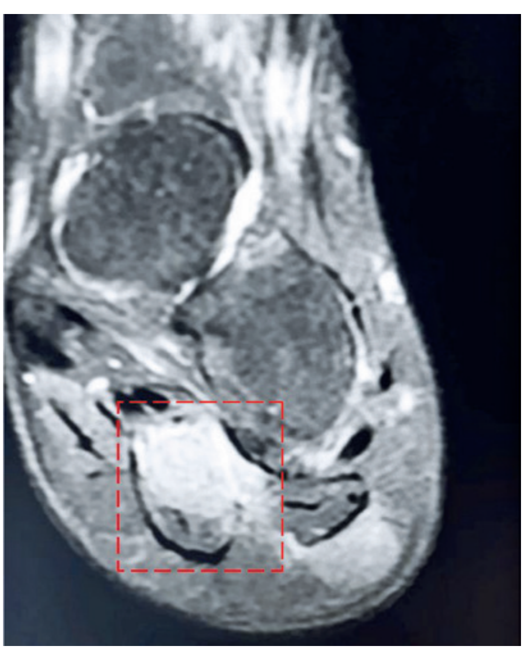

Figure 4. Axial section of the midfoot showing hypersignal image after contrast enhancement.

Of the 11 tumors, ten were in the dorsal subungual region of the toes, and only one was found in the plantar region of a toe. Specifically, eight tumors were in the hallux, one in the second toe, and two in the third toe. All cases were managed with extensive tumor resection, and no malignancy was found upon histopathological examination[12].

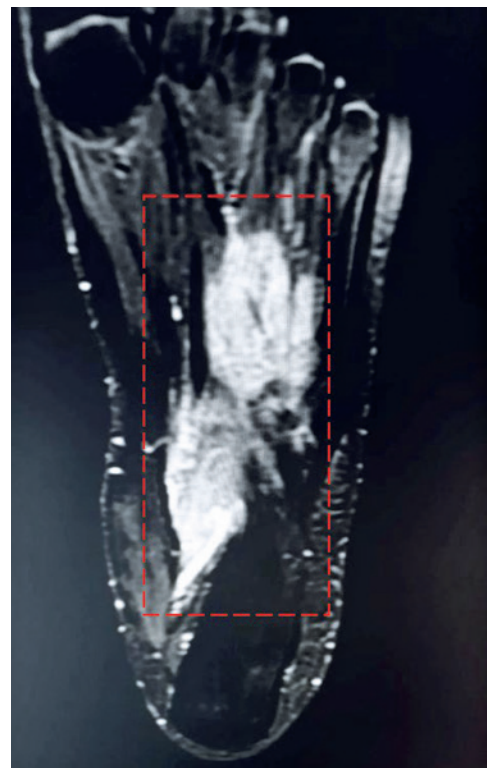

Figure 5. Coronal section of the foot showing mass (marking in the figure) in hyperintense signal after contrast enhancement.

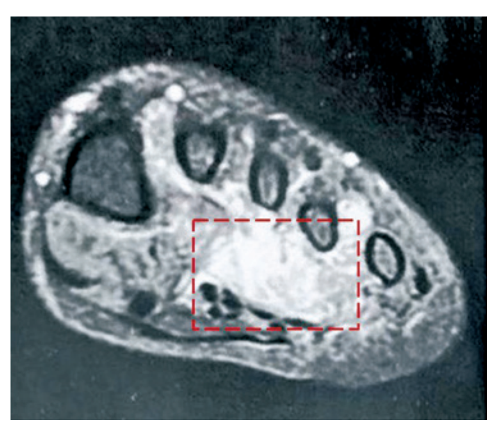

Figure 6. Sagittal section of the forefoot with mass (marking in the figure) in hyperintense signal on T2.

Figure 7. Intraoperative during resection, showing the dissection of the plantar fascia to establish the surgical margin.

Figure 8. Post-resection of tumor lesion, showing large soft tissue resection.

Rkiba et al.[13] published a case in 2021 involving a malignant GT of the foot. The patient was a 64-year-old woman who had noticed a growing and painful plantar mass in the right forefoot over a period of six months. The MRI revealed a large mass measuring 8 cm, centered in the plantar region with dorsal extension. An incisional biopsy confirmed a malignant GT with a high degree of anaplasia. Due to the tumor's aggressiveness and extensive local infiltration, wide local resection would be insufficient, and the surgical team opted for a transtibial amputation. As with the case presented in our report, staging did not reveal metastases, and therefore, no adjuvant oncologic treatment was indicated.

According to the authors, a thorough evaluation of any mass on the plantar surface of the foot is paramount, especially considering the possibility of tumors with atypical etiologies, such as GTs, beyond the more commonly encountered conditions like plantar fibromatosis. While plantar fibromatosis is typically benign, certain cases—such as GTs—may carry a risk of malignancy and metastasis, requiring a careful and precise diagnostic approach. Accurate differentiation between these conditions is essential for developing an effective treatment plan, as early detection of tumors with malignant potential can significantly improve patient outcomes and prognosis.

Figure 9. Plantar surface of the foot showing longitudinal access with dehiscence of the middle third of the wound and presence of ulceration on the lateral surface of the foot.

Conclusion

Glomus tumors in the feet pose significant challenges due to their rare occurrence and the complexity of diagnosis. The reported case aligns with the diverse clinical presentations of these tumors described in the literature. It is crucial to acknowledge the potential for atypical localization and the possibility of malignant transformation, reinforcing the need for a high index of suspicion and thorough diagnostic evaluation in cases of persistent, unexplained foot pain or masses.

Authors' contributions: Each author contributed individually and significantly to the development of this article: ECM *(https://orcid.org/0000-0002-8120-1888), and MCCMS *(https://orcid.org/0009-0008-7578-2250), and GJM *(https://orcid.org/0009-0000-0014-3325) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process; EASJ *(https://orcid.org/0000-0002-5054-874X) 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

Plantar closing-wedge calcaneal osteotomy for the treatment of plantar ulcers in diabetic foot: a case report

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Abstract

Calcaneal ulcers in the diabetic foot present a complex challenge in limb preservation, as most of the outcomes are calcanectomy or limb amputation. These outcomes can significantly impact the patient, leading to functional limitations and difficulties with orthotic use. We report a case of the adaptation of a technique previously described by Gaenslen in 1931 for the treatment of calcaneal osteomyelitis. A 51-year-old diabetic patient with chronic injury in the calcaneal plantar region. Previous ulcers and debridements made primary closure challenging. A plantar subtraction osteotomy of the calcaneal bone was performed, facilitating primary chronic wound closure. The technique proved to be effective in treating calcaneal ulcer of a diabetic patient, preventing amputation, and promoting rehabilitation, in addition to enabling the early return of the patient to work activities.

Level of Evidence IV, Therapeutic Study; Case Report.

Keywords: Diabetic foot; Osteomyelitis; Osteotomy; Amputation; Ulcer.

Introduction

The prevalence of diabetes mellitus (DM) worldwide will be 783 million people by 2045, and it is estimated that 15% of this population will have diabetic foot ulcers at some point in the disease, and the outcome may be amputation in up to 30% of cases[(1)].

Calcaneal bone involvement in diabetic foot ulcers presents a significant challenge, as factors such as reduced vascularity, loss of the plantar cushion, and reduced protective sensation complicate treatment. In these cases, maintaining hindfoot functionality, securing calcaneal tendon fixation, and achieving primary wound closure are often difficult[(2)].

Currently, the most accepted treatment for calcaneal ulcers is the combination of debridements, calcanectomy, and less invasive procedures to preserve functional structures[(3)]. However, osteotomies are also alternatives to manage diabetic foot ulcers, as described by Gaenslen in 1931, involving a sagittal incision to perform an osteotomy with plantar resection of the affected portion of the calcaneus[(4)].

The objective of this study is to report a case of calcaneal plantar osteotomy in a diabetic foot, performed to treat ulceration in this region. The technique, successfully adapted from the method originally described by Gaenslen, allowed primary wound closure with lower morbidity and early return to usual activities.

Case report

A 51-year-old diabetic patient was diagnosed with type 2 for five years and on insulin for one year. The patient reported a wound in the plantar region of the left calcaneus two months prior, although unable to inform if it originated from a callus or contusion. Despite undergoing dressings and debridements, the wound showed no signs of improvement (Figure 1A). In previous specialized care, surgical procedures were suggested, such as vascularized flaps, calcanectomy, and even amputation. Upon admission to our service, the patient presented pain, hyperemia, and purulent discharge with a foul odor through the wound. Laboratory tests were as

Study performed at the Hospital Alemão Oswaldo Cruz, São Paulo, Brazil.

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follows: Hemoglobin 13.8 g/dL, leukocyte count 11100%/mm3, C-reactive protein 5.53 mg/dL. On imaging tests, both radiography and nuclear magnetic resonance (NMR) of the ankle showed no changes in the calcaneal bone. In the NMR, no signs suggestive of osteomyelitis were found (Figures 1B and 1C). Doppler arterial ultrasound showed significant obstruction of popliteal flow and tibiofibular trunks. Revascularization was performed but was insufficient, with permanence of posterior and anterior tibial artery stenosis, without filling the plantar arch (Figure 2A and 2B). To control soft tissue infection, debridement was performed with material collection for culture, maintained using negative pressure therapy due to plantar area exposure of the calcaneus, concomitant with intravenous antibiotics (Figure 2C and 2D).

In the samples collected for microbiological evaluation, *Enterococcus faecalis* bacteria were growing in soft tissues, but there was no growth in bone fragments. Antimicrobial therapy with Teicoplanin 400 mg/day was maintained for two weeks. After discussing the case with the patient and family members, it was decided to preserve the limb by a plantar subtraction calcaneal osteotomy for primary wound closure.

With the patient in the prone position, devitalized tissues were removed from the plantar wound, and a proximal portion of the plantar aponeurosis was resected. During the procedure, meticulous care was taken to identify and protect the adjacent anatomical structures. Medially, this included the posterior tibial nerve and its branches, the posterior tibial

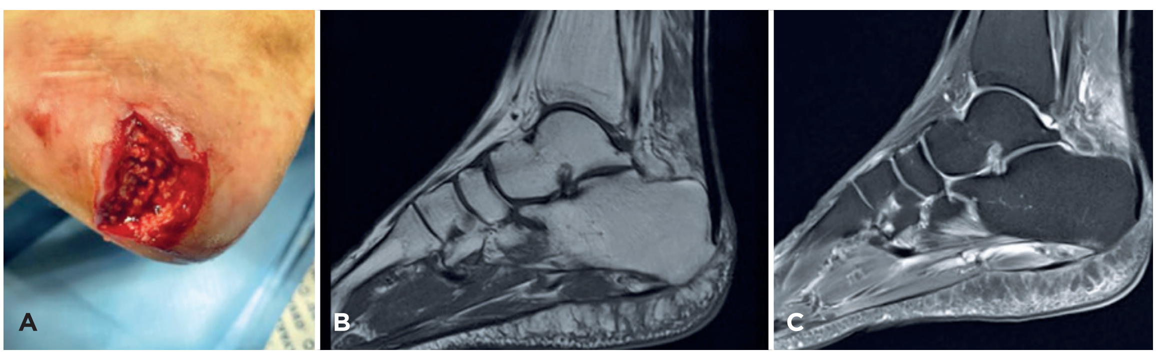

Figure 1. (A) Clinical photo of the plantar portion of the calcaneus after initial debridement. (B) Magnetic Nuclear Resonance Imaging (MRI) – Sag T1. (C) Magnetic resonance imaging – Sag T2. MRI images show mild edema and liquid slides in the adjacent fat pad but without extension to the deep bone plane or signs of osteomyelitis.

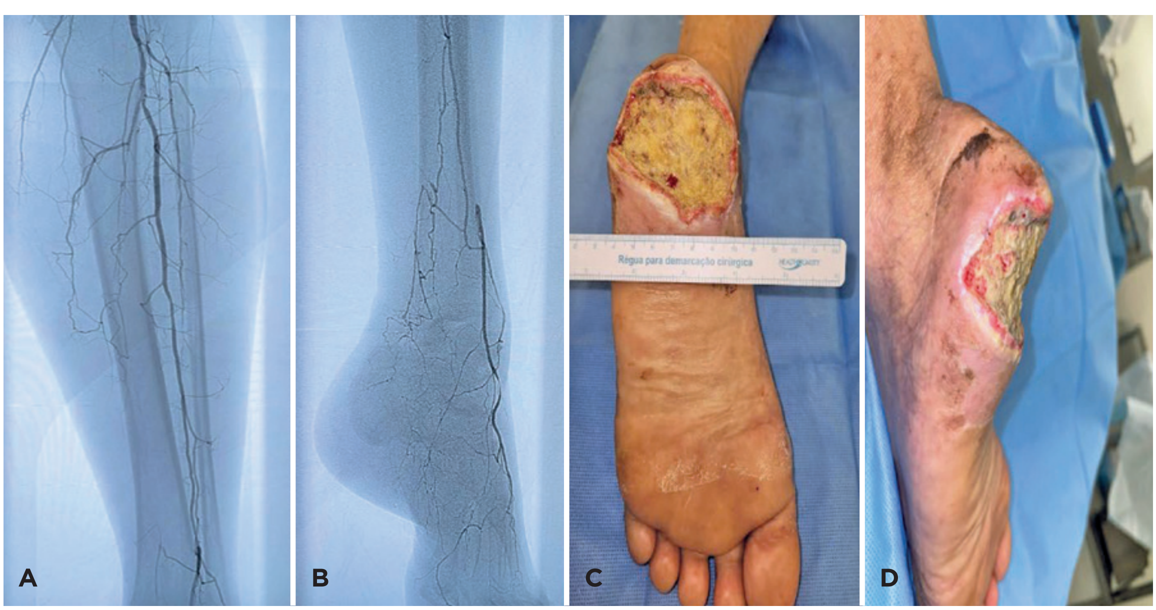

Figure 2. (A and B) Arteriography images after angioplasty, presenting obstruction of the anterior and posterior tibial arteries in the leg, only patent fibular artery. In the foot, the plantar arch is incomplete due to obstruction of the plantar arteries and minimal vascularization in the calcaneous, with only the dorsalis pedis artery remaining patent. (C and D) Clinical photo after surgical approach.

tendon, the flexor hallucis longus, and the flexor digitorum longus. Laterally, the peroneal tendons and the sural nerve were safeguarded. Under radioscopic guidance, the site for the plantar subtraction osteotomy was marked as a triangular region on the calcaneus, with the base at the plantar surface and the apex just below the subtalar joint (Figure 3A).

The marked area was resected using a saw, preserving the superior cortical bone. Radiological control in the sagittal plane was performed, followed by osteotomy closure and provisional fixation with two guidewires (Figure 3B). Final fixation was then completed using two cannulated screws (Figures 3C and 3D). Due to the osteotomy closure, the calcaneal tendon was tensioned. To prevent deformity in equinus positioning of the foot, a percutaneous Hoke-type tendon lengthening was performed. Intraoperative radioscopic control (Figures 3E and 3F) confirmed that the fixed osteotomy allowed wound edge approximation and enabled primary ulcer closure (Figure 4A). A negative pressure incisional dressing was applied, and the limb was immobilized using a suropodalic splint, with the ankle maintained at 90 degrees.

The lesion was reassessed after one week in a sterile environment (Figure 3B). The patient was discharged with a standardized antimicrobial therapy and instructed to maintain immobilization and avoid weight-bearing for three weeks. After this period, a physiotherapy program was initiated to restore the range of motion and muscle strengthening. Stitches and immobilization were removed in the third week. However, in the fourth week, the patient developed wound dehiscence in the medial region of the calcaneal along with the appearance of a fistula at the site of the medial calcaneal screw, which was attributed to screw protrusion (Figures 4D and 4E). An attempt was made to close the wound using silver dressings over two weeks, but without success. Given the persistence of the lesion, a new surgical intervention was performed, involving the removal of the medial cannulated screw and suturing to approximate the wound edges (Figure 4F). Despite the initial difficulty in wound closure, the lesion completely healed with no fistulas or secretion discharge formation. Starting in the tenth week, the patient began progressive physiotherapy focused on gradual muscle strengthening, proprioception, and partial weight-bearing, using insoles and footwear designed for insensitive feet. By the sixth month, the patient had returned to work without walking limitations, showing progressive improvement in mobility. At the one-year follow-up, radiographic exams confirmed osteotomy consolidation (Figures 5A and 5B), and the patient demonstrated a very satisfactory clinical outcome (Figures 5C, 5D, 5E, and 5F).

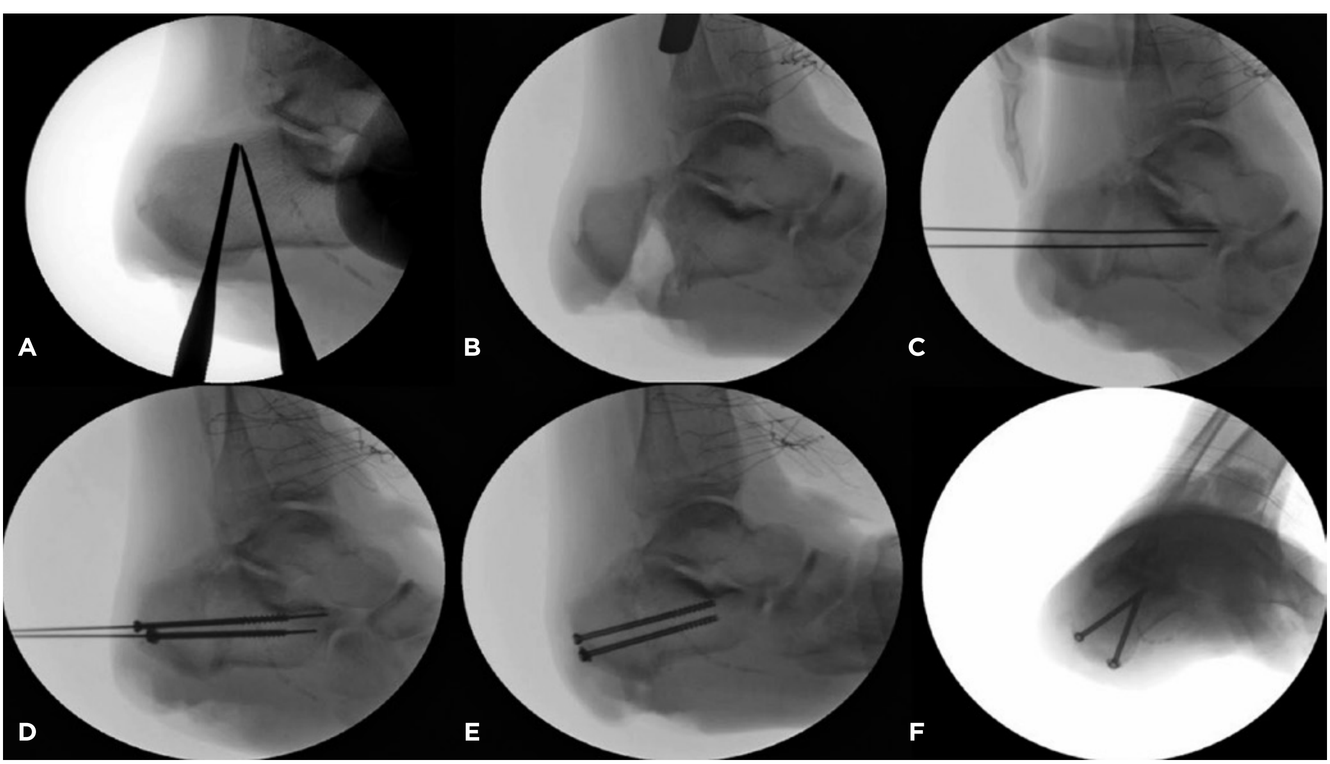

Figure 3. (A) Osteotomy marked area. (B) Plantar resection osteotomy performed. (C) Osteotomy closure and guidewire passage. (D) Osteotomy fixation with cannulated screws. (E and F) Intraoperative control of osteotomy fixation.

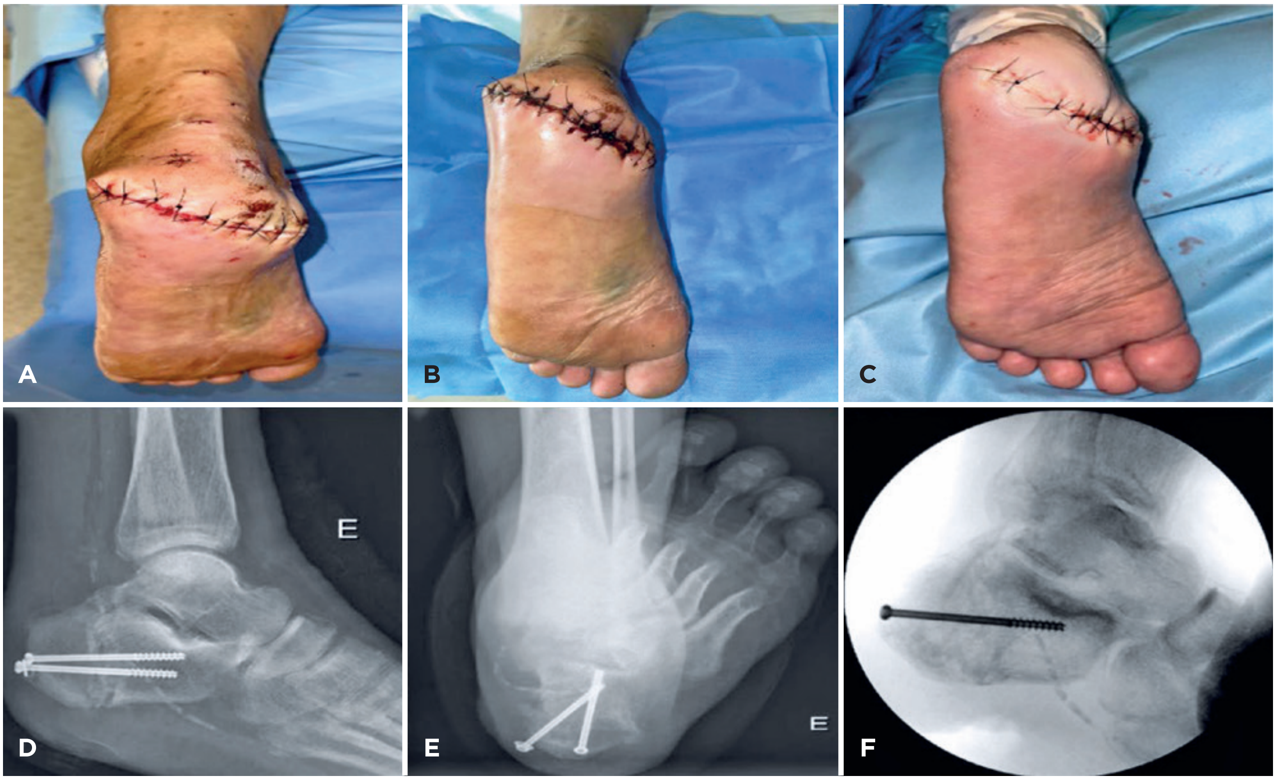

Figure 4. (A) Suture in the immediate postoperative period. (B) One week surgical wound. (C) Suture after revision wound and removal of a cannulated screw after six weeks. (D) Profile calcaneal radiography and (E) Axial calcaneal radiography, observed loosening of one cannulated screw. (F) Intraoperative control of removal of one screw.

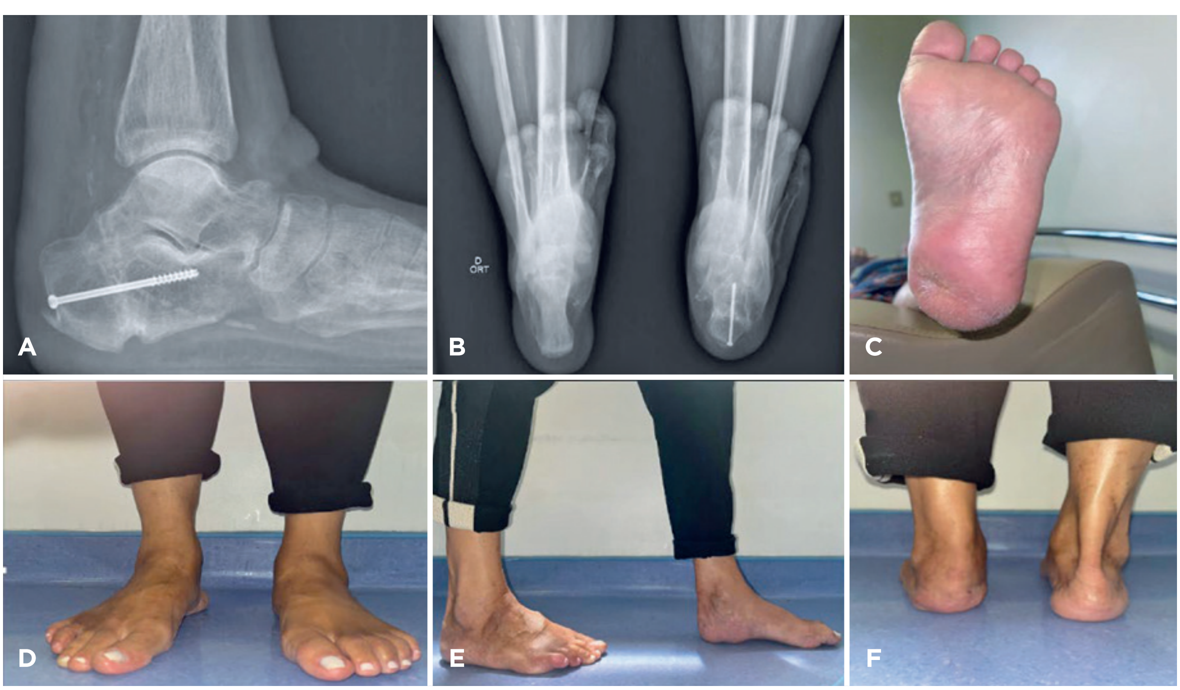

Figure 5. (A) Profile calcaneal radiography after 12 months (B) Bilateral Saltzman radiography after 18 months. (C) Healed wound. (D, E, and F) Clinical photos of the patient's foot, performing weight-bearing.

Discussion

This case report highlights the challenges involved in achieving wound closure in diabetic foot ulcers, emphasizing the importance of choosing treatments that prevent unsatisfactory outcomes for patients. Diabetic foot ulcers represent a significant source of morbidity, mortality, and socioeconomic burden in the Western world. Approximately 60% of these ulcerations are infected with polymicrobial flora, and up to 20% of moderate to severe diabetic foot ulcers may lead to amputation, with associated mortality rates reaching as high as 30% within five years[(5)].

The synergistic effect of diabetic sensory, motor, and autonomic dysfunctions results in foot deformities and viscoelastic alterations in the skin. Combined with repeated microtrauma, these changes lead to callus formation, which progressively extends deeper into the soft tissues, ultimately involving the bone[(5,6)].

In diabetic foot, the calcaneus is the second most frequently affected area by ulcerations[(6)]. Managing ulcers in this location is particularly challenging for limb preservation, as this region experiences significant pressure from body weight and has limited options for vascularized flap coverage[(6,7)]. Literature indicates that such ulcerations often progress to osteomyelitis, resulting in prolonged antibiotic use, length of hospital stay, and higher overall treatment costs. Therefore, accurate diagnosis is essential for effectively preventing and managing diabetic foot infections[(7)].

Although the definitive diagnosis of osteomyelitis is microbiological, several tests can increase the predictive accuracy for this condition, including radiographs, MRI, and the probe-to-bone test[(2,7)]. In our case, the probe-to-bone test was positive despite the absence of clear signs of osteomyelitis or definitive bone involvement on imaging studies. This suggests that the timely intervention performed prevented further progression of the disease.

Calcanectomies have been advocated as procedures aimed at preventing transtibial or transfemoral amputation in patients presenting with contiguous and recurrent infections, as these amputations not only increase morbidity and mortality but also constitute significant risk factors for subsequent amputations[(2,8)]. A functional limb capable of ambulation with the use of orthoses can be achieved, but the adaptation process for patients is not always straightforward[(2)].

Alternative limb-preserving surgical treatments for calcaneal ulcerations and osteomyelitis include using muscle flaps to fill bone defects following debridement[(9)]. However, in our case, stenoses of adjacent vessels made the use of vascularized flaps unfeasible. As a result, a plantar resection osteotomy was chosen as an effective alternative, enabling primary wound closure while preserving the Achilles tendon insertion.

Unlike the original technique described by Gaenslen, whose incision was to plantar sagittal in the midline[(9)], the approach in our study employed a transverse incision to the midline in the sagittal plane. An important limitation of this study was the fact that the calcaneus was not attached to the bone, which made it possible to fix the osteotomy for early mobility with greater safety and bone consolidation.

Plantar resection osteotomy proved to be an effective alternative for treating calcaneal ulcers, allowing for early rehabilitation, infection control, and primary wound closure. However, future randomized clinical trials are needed to provide a stronger scientific foundation for adapting the Gaenslen technique.

Authors' contributions: Each author contributed individually and significantly to the development of this article: CDF *(https://orcid.org/0000-0002-6649-2066) Interpreted study results, participated in the review process; FDPR *(https://orcid.org/0009-0007-9143-1162) Interpreted study results, participated in the review process; MLSK *(https://orcid.org/0009-0009-9003-0863) Interpreted study results, participated in the review process; DAS *(https://orcid.org/0009-0008-8395-8797) Interpreted study results, participated in the review process; EAP *(https://orcid.org/000-001-60088671) Interpreted study results, participated in the review process. ECSS *(https://orcid.org/0000-0001-5018-3923) Conceived and planned the activities that led to the study, wrote the article, participated in the review process, approved the final version; interpreted study results, participated in the review process; and participated in the review process; All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID).

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Case Report

Total ankle replacement with antibiotic-impregnated cement: a case report on the infected ankle management

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Abstract

Ankle fracture infection is a devastating complication that can lead to chronic pain, limited motion, post-infectious end-stage ankle arthritis, osteomyelitis, and amputation. Treatment historically involves aggressive debridement, hardware removal, and long-term antibiotic therapy. We describe a case of post-infectious end-stage ankle arthritis treated with a custom, fixed-bearing, 3D printed total ankle replacement with antibiotic-impregnated cement. The provided treatment allows continued elution of high-dose local antibiotics while preserving the ankle range of motion and allowing immediate weight bearing postoperatively.

Level of evidence V; Therapeutic studies; Expert opinion.

Keywords: Arthroplasty, replacement, ankle; Arthritis, reactive; Antibiotic prophylaxis; Bone cements.

Introduction

Infection following an ankle fracture is a dreaded complication that can lead to post-infectious arthritis, pain, limited range of motion, and even amputation. Treatment goal is the eradication of the underlying infection while preserving ankle function. Traditional treatment strategies after infection have involved aggressive surgical debridement, implant removal, and prolonged antibiotic therapy[1]. In the setting of end-stage ankle arthritis with underlying osteomyelitis, standard treatment is a two-stage procedure with implant removal, debridement, and placement of a temporary static cement spacer prior to definitive management. More recently, there has been a trend towards using static antibiotic cement spacers as definitive treatment[2]. Articulating antibiotic spacers for treating ankle infections has also been recently described in the literature with improved outcomes and possibility for use as a definitive treatment[3].

Over the past decade, there has been an increased use of 3D printing to create custom lower extremity implants, particularly in the setting of severe bone loss. As total ankle replacement (TAR) continues to increase in popularity for the treatment of end-stage ankle arthritis, there has also been an increase in patient-specific instrumentation for TAR procedures[4,5]. Novel techniques using 3D printing to design custom talar articulating cement spacers have been described, with promising short-term outcomes[6]. Currently, however, there are no prefabricated TAR spacers on the market. We present a case of post-infectious ankle arthritis in a 14-year-old patient treated with a custom 3D printed component for TAR with antibiotic-impregnated cement (TAR-AIC). Our technique allowed for immediate weight bearing and preserved range of motion, providing continued elution of antibiotics. To our knowledge, this technique has not been previously described in the literature.

Case description

The patient and his family provided consent for the reporting of this case. Patient was a 13-year-old male with no medical history who sustained a type III, open, right bimalleolar ankle fracture after an all-terrain vehicle accident. He was initially treated at an outside hospital with irrigation and debridement and closed reduction. Three doses of intravenous antibiotics were administered during initial hospitalization; however, timing of antibiotics administration is not documented

Study performed at the University of North Carolina at Chapel Hill, Chapel Hill, North Carolina, USA.

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in external records nor was tetanus administered. Patient underwent operative fixation nine days after initial injury. His postoperative course was complicated by superficial wound infection. At 25 days postoperatively, patient underwent irrigation and debridement and removal of medial hardware, with intraoperative culture growing *Klebsiella oxytoca*, *Raoultella ornithinolytica*, and *Pseudomonas aeruginosa*. Five weeks after initial injury, patient presented to our medical center with fever, nausea, and vomiting. He had elevated inflammatory markers, purulent drainage from his medial ankle incision, and an MRI concerning for osteomyelitis at that time (Figures 1 and 2). At our institution, patient initially underwent irrigation and debridement of his medial ankle wound. The lateral wound was overall healing well, with superficial wound dehiscence without deep tracking or purulence. Given the acuity of injury and well-appearing lateral incision, it was decided to leave the fibular plate in place with plans for later removal after the fibular fracture bony union. Intraoperative cultures grew *Pseudomonas aeruginosa*. Patient was treated with four weeks of intravenous antibiotics before switching to oral antibiotics in the setting of a developing leukopenia. He then underwent a planned repeat debridement and removal of his fibular plate one month after initial debridement.

In the year following his injury, patient had post-infectious end-stage arthritis, continued ankle pain, and limited mobility, requiring the use of a cane (Figure 3). Inflammatory blood markers had normalized. An MRI and a tagged white blood cell scan were obtained to evaluate a possible residual osteomyelitis and were reassuring. At this point, patient was 14-years-old and his physes were closed on radiographs, with CT imaging demonstrating a remodeling of the fibula and partial union of the medial malleolus. Patient and his family declined to have ankle fusion or amputation after discussion, requesting another discussion on a joint sparing procedure. After extensive conversation with patient and family, decision was made to proceed with a custom TAR-AIC. Patient and family understood that the TAR-AIC surgery results would be unpredictable, but they wished to avoid an ankle fusion and chose to proceed.

A CT scan was performed in accordance with computer-aided design (CAD) parameters. Bilateral lower extremities were scanned to allow the unaffected side to be mirrored and serve as the basis for implant design. Slice spacing was less than 1.25 mm, with a pixel size of 0.5 mm. Analyses were

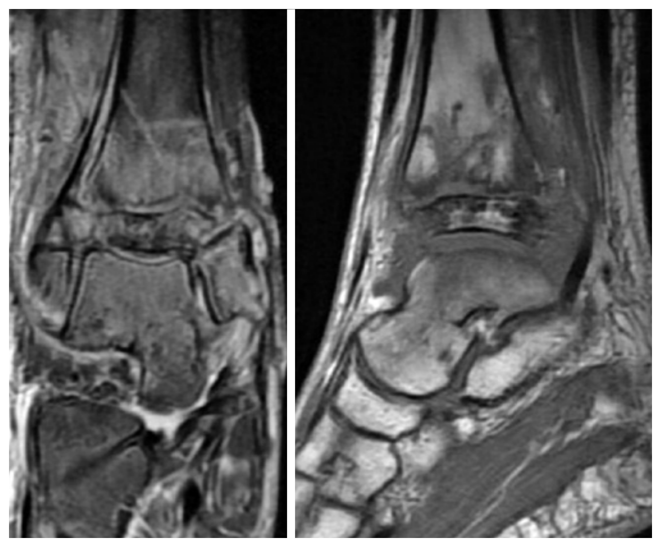

Figure 2. Right ankle MRI concerning for osteomyelitis upon initial presentation to our medical center.

Figure 1. Clinical photography of patient's right ankle upon initial presentation to our medical center, with purulent drainage from the medial ankle incision and superficial lateral incision dehiscence.

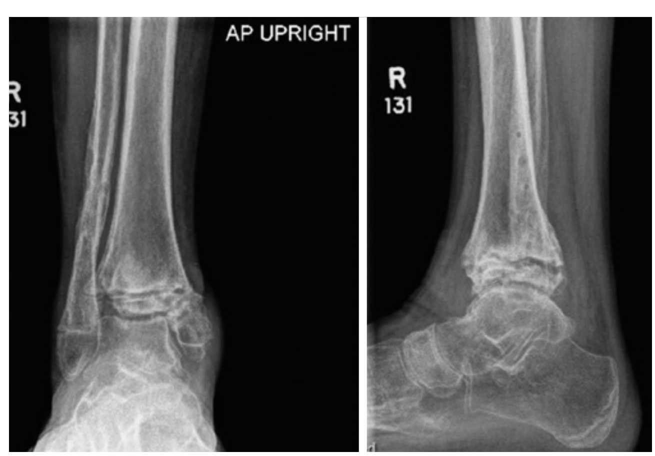

Figure 3. Preoperative anteroposterior and lateral right ankle radiographs demonstrating severe end-stage post-infectious arthritis.

performed in digital imaging and communications in medicine (DICOM) files within a timeframe where no significant change in patient anatomy had occurred. Implants were fabricated by Restor3d Inc. (Durham, NC) by selective laser melting (SLM) of cobalt chrome alloy (CoCrMo). Our design incorporated a stacked gyroid component to facilitate antibiotic cement impregnation. In terms of surgical technique, the custom TAR-AIC followed an approach similar to a patient-specific TAR procedure. We utilized an anterior approach to the ankle. We prepared the antibiotic cement by mixing 2 g of tobramycin with Simplex bone cement (Stryker, Limerick, Ireland) until it reached the appropriate consistency. Prior to implantation, the gyroid infill of the tibial and talar components were packed with the antibiotic-impregnated bone cement (Figure 4). An appropriately sized standard polyethene component was placed, and the ankle was found to be stable. The final implant fluoroscopic imaging can be viewed in Figure 5. A multilayer closure with monofilament suture was done. A negative pressure wound vac was applied. A compression wrap was applied as previously described by Schipper et al.[7] Postoperatively, weight bearing was immediately allowed as tolerated in a controlled ankle movement (CAM) boot. Patient underwent no further surgical procedures to date.

At six months postoperatively, patient reported no limitation in activities, being able to ambulate without an assistive device and engage in running activities. Patient's

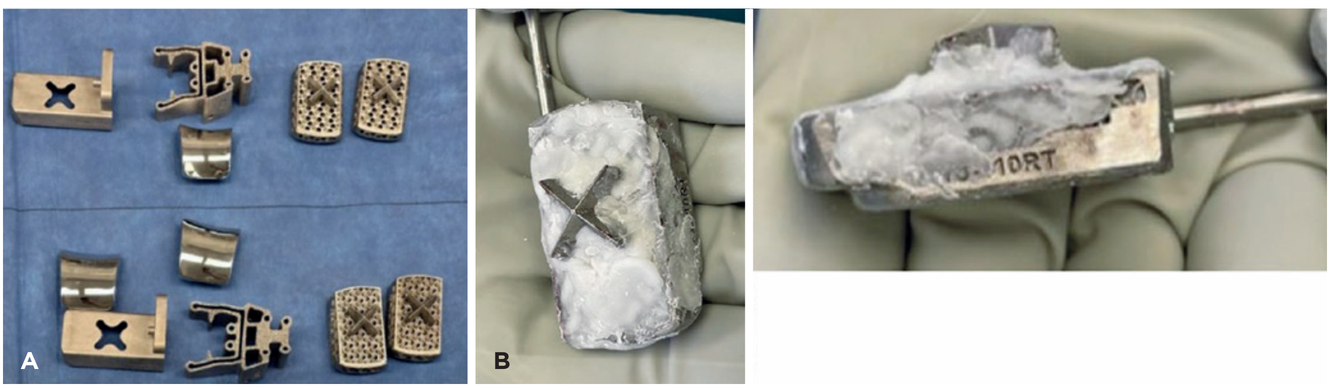

Figure 4. Total ankle arthroplasty components with gyroid tibial and talar components before (A) and after (B) impregnation with bone cement.

Figure 5. Intraoperative fluoroscopic radiographs of right total ankle replacement with antibiotic-impregnated cement (TAR-AIC).

American Orthopaedic Foot & Ankle Society (AOFAS) scores had improved from 46/100 preoperatively to 83/100 at six months, and his ankle dorsiflexion range of motion was 15 degrees, while plantarflexion range of motion was 30 degrees. Radiographic parameters showed no signs of implant failure, loosening, or change in alignment (Figure 6). The radiolucency visualized around the tibial component represent the cement mantle and remained stable compared to intraoperative fluoroscopy. Intraoperative cultures remained negative. At 17 months postoperatively, which was the last follow-up to date, patient continued to do well clinically, with no signs of infection recurrence. Radiographs at that time demonstrated minor tibial component subsidence and stable cement mantle at the perimeter of the tibial component. There was a stable, anatomic alignment of his custom total ankle (Figure 7).

Figure 6. Postoperative anteroposterior and lateral radiographs at six months, with stable positioning of implants, stable alignment, and stable cement mantle.

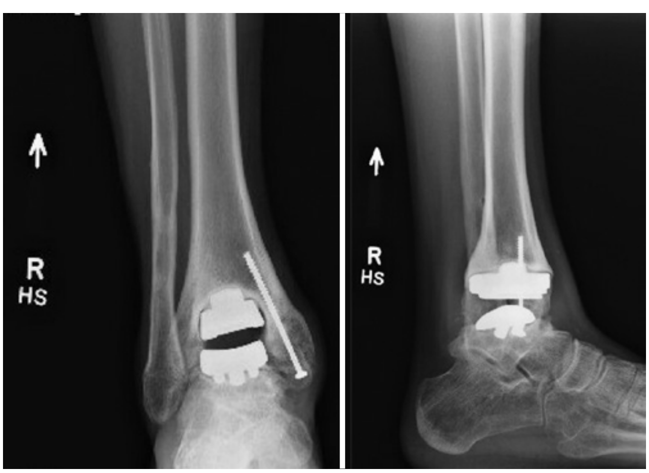

Figure 7. Postoperative anteroposterior and lateral radiographs at 17 months, with stable total ankle component alignment and minor tibial component subsidence.

Discussion

We present a case demonstrating the utilization of 3D generated prostheses for treatment of post-infection ankle arthritis. The TAR-AIC represents a potentially substantial advancement in the management of ankle infections.

With total ankle arthroplasty on the rise in the treatment of end-stage ankle arthritis, periprosthetic infections of TAR are also increasing, with infection rates cited at 2.4%–3.2%[8]. Infected TAR is a devastating complication, with current standard treatment for chronic infection being a two-stage revision with explantation of hardware, debridement, and placement of an antibiotic spacer followed by six to eight weeks of IV antibiotics prior to reimplantation of total arthroplasty components versus ankle or tibiotalocalcaneal fusion[9,10]. A single-stage procedure avoids a prolonged non-weight bearing status, additional procedures, and associated risks and expenses, potentially improving the quality of life. Tibiotalocalcaneal fusion with antibiotic-coated nails has been described as a single-stage procedure for infected ankle fractures and infected TAR with good functional outcomes[10]. However, with further research and continued technological advancements, TAR-AIC has the potential to become the gold standard for the treatment of infected TAR. This innovative approach combines the benefits of joint replacement and continued antibiotic elution. Our technique may allow for a single-stage procedure with local antibiotic delivery, early mobilization, and preserved ankle range of motion. Despite the promising results, challenges remain in the implementation of TAR-AIC. The cost of custom implants should be considered. Furthermore, long-term follow-up studies are needed to evaluate the durability and longevity of the implant.

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