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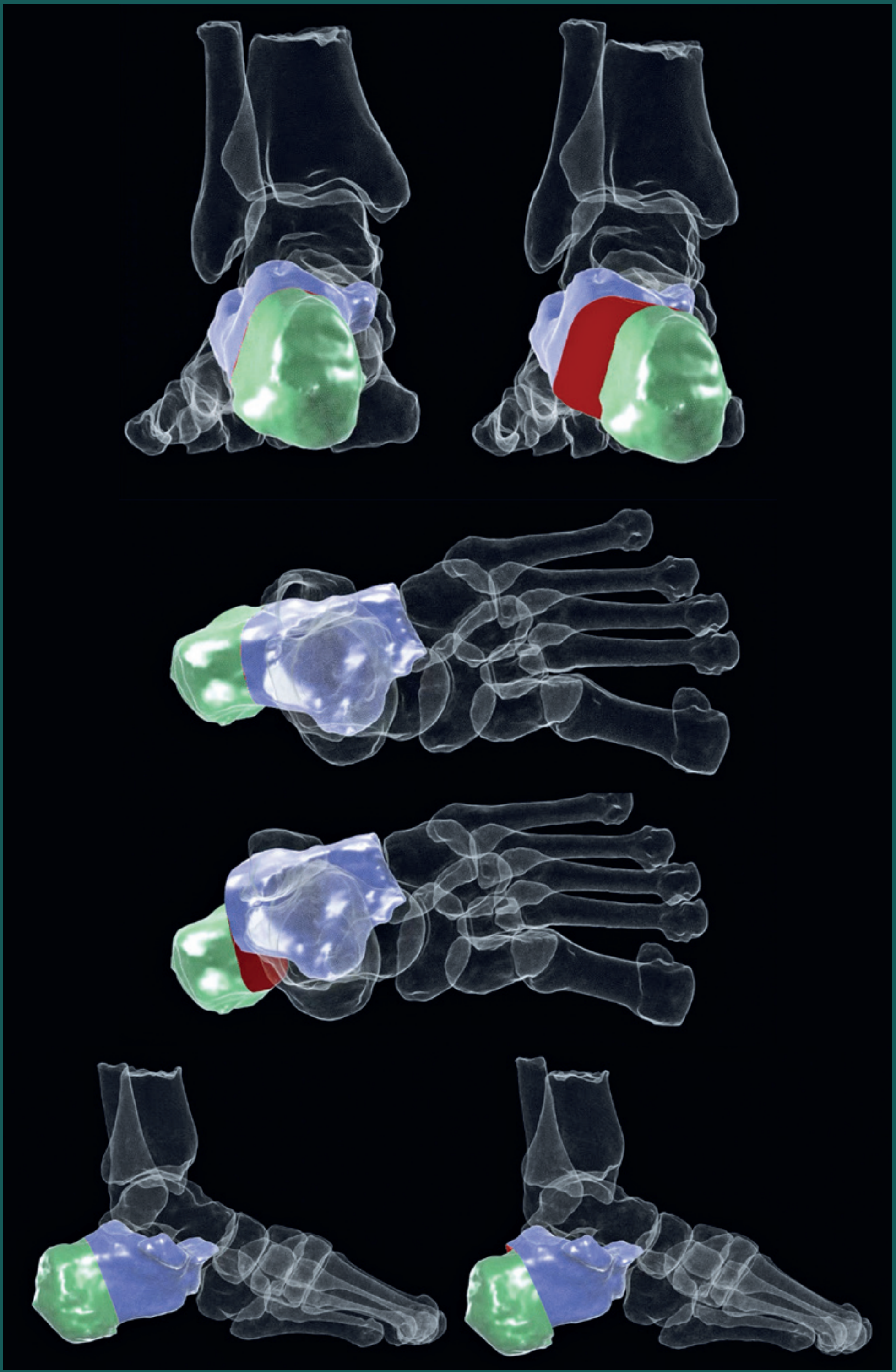

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Editorial

JOURNAL OF THE Foot & Ankle JFA

CAIO NERY, M.D.

ESCOLA PAULISTA DE MEDICINA

HOSPITAL ISRAELITA ALBERT EINSTEIN

My deepest gratitude...

My first expression as Editor-in-Chief of the **Journal of the Foot and Ankle** is one of deep gratitude for the opportunity that is being given to me by the Editor Emeritus and now President of ABTPé, Prof. Dr. Alexandre Leme Godoy-Santos and our colleagues from the board of Associate Editors who elevated me to this position. My gratitude also extends to ABTPé, which, through successive directorships, has been providing support and encouragement to the maintenance and growth of our journal.

The task we undertake is challenging and immense—it depends on everyone's participation, from the most renowned professional who allows himself to publish with us to the most novice student who aspires, one day, to have his name written on our pages so that his ideas can be known to everyone. It depends on the altruism and tenacity of authors, reviewers, translators, correctors, layout designers, and technical editors to achieve the desired indexing. We have already been much further from achieving this goal than we are now, but we still have a long way to go! Let's accomplish this together.

In addition to a new system for submitting and evaluating articles, more in line with the major international scientific journals, we will include in each issue review articles whose main virtue will be to update professionals who are working daily and instruct young doctors who are still preparing to participate in this toil.

I urge everyone to read, disseminate, discuss, criticize, and share the learning we bring to our pages with your colleagues, residents, and students. We will consolidate the position of the **Journal of the Foot and Ankle** as a viable and practical alternative for disseminating your research.

Welcome...we need everyone's help!

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Special Article

Surgical treatment for talus osteochondral lesions: What's new?

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Abstract

Osteochondral lesions of the talus (OLTs) are a common pathology encountered by foot and ankle surgeons. Symptomatic cartilage lesions in the ankle pose a significant challenge and often require surgical intervention to alleviate pain, improve joint function, and restore the integrity of the articular surface. Possible treatment options, including operative and nonoperative management, have been widely discussed in the literature, with substantial heterogeneity regarding treatment approaches and resulting patient-reported outcomes and joint function metrics. A general problem regarding OLT is that this entity is not clearly defined, nor its description, location, or best treatment for each type that may be required in some symptomatic presentations. The focus of our paper was to show the proper treatment for each lesion, including location, deepness, vascularity, and capability of healing.

Level of evidence V; Expert opinion.

Keywords: Osteochondral; Talus/injuries; Talus/surgery; Arthroscopy; Ankle.

Introduction

Osteochondral lesion of the talus (OLT) describes damage to the talar cartilage, including pathological changes in the underlying bone. In nearly 80% of patients with OLT, a history of ankle trauma can be found[1,2], and 38% present ankle ligament laxity. In addition, 39% of patients with ankle instability can present OLT[3,4]. Subsequently, acute trauma and repetitive micro-trauma due to ankle instability and/or hindfoot malalignment seem to be a leading cause of OLT. In an ankle with chondral damage, the synovial fluid penetrates these micro-chondral lesions, infiltrating the subchondral and bone marrow area and leading to bone edema. The joint load increases the fluid pressure that can induce failure of the chondral bone support and, later on, cyst formations[5].

A general problem regarding OLT is that this entity is not clearly defined, nor its description, location, or best treatment for each type that may be required in some symptomatic presentations. The focus of our paper was to show the proper treatment for each lesion, including location, deepness, vascularity, and capability of healing.

Diagnosis

Osteochondral lesions of the talus predominate in males, mostly affecting patients over 30 years. Patients typically present symptoms from six to 12 months after an initial trauma (ankle fracture or sprain); typical symptoms are deep ankle pain, tenderness, and swelling in the medial or lateral gutters of the ankle that increases with weight-bearing and sports activity. Occasionally, patients report locking or catching sensations in the ankle. Frequently, recurrent sprains and unbalanced loading of the entire foot coincide with the ankle problem. Like any other condition, a thorough clinical

Study performed at the Hospital Felício Rocho, Belo Horizonte, MG, Brazil.

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examination should be performed to identify tenderness, swelling, limitations of ankle normal movements, subtalar and talonavicular range of motion, ankle ligaments stability, and hindfoot alignment.

However, none of the clinical findings are specific enough to diagnose OLT securely; hence, the diagnostic procedure should include imaging exams and plain radiography of the ankle using the anterior-posterior, lateral, and mortise views as a first examination. Computed tomography (CT) allows better visualization of bony parts of the lesion but with the inconvenience of high radiation exposures and less information on cartilage wear. Magnetic resonance imaging (MRI), on the other hand, can evaluate the OLT activity and possible accompanying tendons and ligament injuries better, but it may overestimate the size and diameter of the cartilage lesion when compared to arthroscopy[1].

Verhagen et al. showed that MRI has a higher sensitivity than CT (0.96 versus 0.81) to detect OLT and is thus the tool of choice to evaluate when a plain radiograph is negative, but these methods are complementary[2]. Besides the diagnostic utility of MRI and its better capacity to analyze the level of damage to the cartilage, it has an important prognostic and follow-up value in evaluating its regeneration after reparative and regenerative surgical treatments, in a kind of noninvasive biopsy, depending on collagen fiber network organization, water coordination, and content[3]. In a cohort study, Rizzo et al. demonstrated the good capacity of T2 mapping sequences in providing quantitative information about the newly formed tissue and its differences from the native cartilage[4].

Magnetic resonance imaging

Magnetic resonance imaging is the imaging technique of choice since it provides excellent visualization of the articular cartilage, subchondral bone, and adjacent soft tissues; it has a sensitivity of up to 96% and a specificity of 96%–100%. There is a close correlation of MRI findings and grading with arthroscopic findings, along with good interobserver agreement. MRI also demonstrates a sensitivity of 97% and specificity of 100% for identifying unstable lesions, and it is superior to CT for identifying early-stage lesions limited to the articular cartilage. The perceived disadvantage of MRI is due to the presence of bone marrow edema in the acute stage, which may lead to overestimation of lesion size or obscure lesion margins, information that may be required for surgical planning.

Nuclear medicine

Although bone scintigraphy is no longer utilized in the management of OLT due to the lack of specificity, the single photon emission computed tomography with CT (SPECT-CT) presents a good correlation with image and patient's symptoms, demonstrating that activity on SPECT-CT is more common in patients submitted to intervention compared to those treated conservatively. In patients with multiple lesions, SPECT-CT can also identify the symptomatic lesion due to its activity and help in surgical planning by demonstrating the extent of the lesion. Hence, while it is not considered the primary imaging modality, there is evidence that SPECT-CT can act as an adjunct in surgical planning, especially in the recurrence of pain after first treatment. It has, therefore, been recommended as part of a comprehensive assessment of the abnormality.

Role of imaging in management planning

The role of imaging is to diagnose the lesion and to inform an appropriate treatment pathway. While important factors for clinical decision-making include skeletal maturity, lesion size, and evidence of instability, other lesion characteristics, such as integrity of the overlying cartilage and subchondral changes, are also important to help decide the appropriate surgical intervention. There is a higher healing potential of traumatic OLT in children, with studies showing significant union and good clinical outcomes, but in adults, this lesion rarely heals.

Some authors have stated that OLT defect size is the single most important prognostic factor, and others, such as age, symptom duration, history of trauma, or lesion location, had no association with clinical failure. The choice of intervention is usually dictated by size, with lesions measuring smaller than 10 mm in diameter, less than 100 mm^2 in cross-sectional area, and less than 5 mm in depth are considered ideal for reparative procedures, and larger lesions being more suitable for replacement procedures. However, others have advocated that lesions up to 15 mm in diameter or measuring up to 150 mm^2 can also be treated with reparative techniques. A length of 15 mm or a cross-sectional area of 150 mm^2 is considered a critical cut-off point, with poor clinical outcome associated with larger lesions submitted to debridement and microfracture.

Osteochondral lesions of the talus stability or instability can be assessed by imaging. On radiographs, lesions measuring 0.8 cm^2 are likely unstable, and a sclerotic margin measuring more than 3 mm can be noted. Other signs of instability can be identified in MRI, including a 5 mm or bigger, rounded deep to the lesion, representing a cyst, possibly due to intrusion of joint fluid into the cancellous bone or cancellous bone resorption. These signs of instability are seen in 22% to 31% of patients with an unstable OLT, but 50% demonstrate only one sign of instability on MRI. MRI has proven excellent for detecting an unstable OLT, with sensitivity ranging between 92% and 97%

On MRI, the osteochondral defect (unstable fragment) can also be a viable source of autologous chondral graft to allow chondral reconstruction. However, despite extensive literature on OLT, no studies assess the viability of these fragments on MRI. Autologous osteochondral procedures are recommended for lesions smaller than 2 cm^2, while matrix-induced autologous chondrocyte implantation (MACI) can be performed for defects measuring more than 2 cm^2. Similarly, a bone marrow-derived cell transplant technique is used for lesions bigger than 1.5 cm^2 in area and up to 5 mm deep (Figure 1).

Modern treatments

There are many possibilities for OLT treatment discussed in the literature, encompassing different approaches, patient-reported outcomes, and functional metrics. Constantly, surgeons are looking for new methods that bring back patient's quality of life by reducing pain and preventing evolution to degenerative osteoarthritis. Treatment can be divided into four main categories: cartilage repair, cartilage regeneration, cartilage replacement, and conservative, in which the chosen option depends on the lesion grade, its chronicity, and the presence of symptoms. Asymptomatic cases are often followed with MRI for progression. In our paper, we discuss in more detail only operative treatment options, mainly regenerative strategies.

Cartilage regeneration strategies

Acknowledging that the articular hyaline cartilage is avascular and with limited regeneration capacities, the regenerative methods aim to form new hyaline cartilage more like the native one when compared to the fibrocartilage produced with microfractures[5,6,7]. In this context, they are more suited for larger (> 10 mm in diameter) and deeper lesions (> 5 mm), thus being preferred in advanced cases such as stage IV, cystic lesions, or when there's severe damage to the cartilage[6,8]. More recently, these methods are also being used for mild cases, as we know that maltreated small lesions can progress to bigger due to the inadequacy of the tissue formed by older treatments (Figure 2).

Autologous chondrocyte implantation and matrix-induced autologous chondrocyte implantation

Autologous chondrocyte implantation (ACI) is a 2-step procedure in which cultured chondrocytes acquired from the anterior talus or the non-weight bearing knee cartilage are placed over the defect, followed by its coverage with periosteum. MACI is a second-generation procedure in that instead of periosteum, the implanted chondrocytes are kept in place with a matrix or scaffold containing these cells.

Even though it keeps a 2-step procedure, the matrix usage allows a lower surgical time, morbidity, and, theoretically, more chondrocytes within the defect[9]. Lenz et al. showed significant improvement in the mean American Orthopaedic Foot & Ankle Society (AOFAS) Score – 60 points to 84, Foot and Ankle Activity Measurement (FAAM) of 89%, and an MRI observation of cartilage repair tissue (MOCART) score of 65 points, all with one-year follow-up[10]. Similarly, Schneider

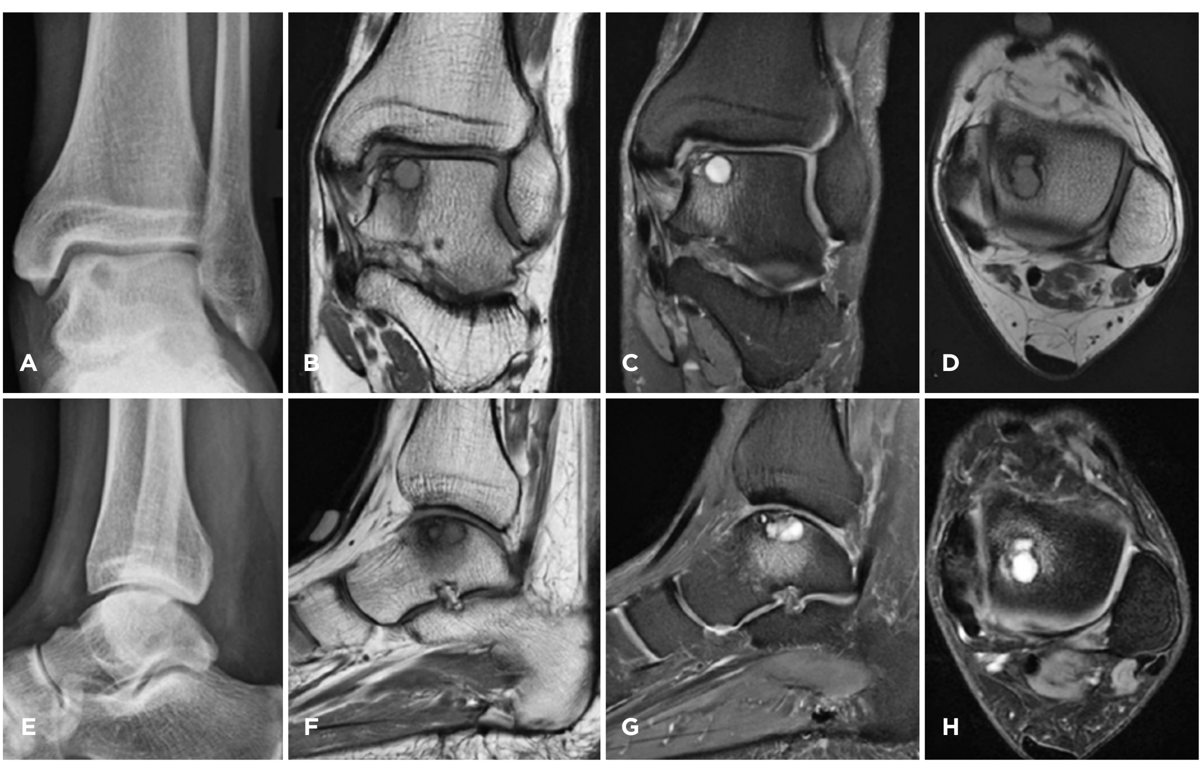

Figure 1. Images of a patient with osteochondral lesions of the talus (Raikin's area 4) with important "prognostic complicating factors": the lesion size, involvement of the shoulder of the talus (unstable lesion), and subchondral cysts. Observing the intense bone marrow edema around the lesion is important, as it is characterized by signal changes on both T1 and T2 images. (A) AP and (E) Lateral - plain ankle radiographs; (B) T1 and (C) T2 coronal views; (F) T1 and (G) T2 sagittal views; (D) T1 and (H) T2, transverse views.

and Karaikudi found very similar results for AOFAS, but after approximately two years of follow-up: 60 (range, 25 to 87) to 87 (range, 41 to 100) ($p < 0.0001$)[11].

Autologous matrix-induced chondrogenesis and arthroscopy-autologous matrix-induced chondrogenesis with heterologous membrane

In 2005, Behrens introduced the autologous matrix-induced chondrogenesis (AMIC) technique[12]. The idea is to achieve the same goal of ACI and MACI through a single session procedure that consists of the combination of microfractures and the application of a porcine collagen type I/III bilayer matrix, used to stabilize the clot formed and hold pluripotent stem cells[6]. It can also be combined with other regenerative methods, like bone marrow aspirate concentrate (BMAC) or platelet-rich plasma (PRP) and minced autologous cartilage graft harvest for the lesion. Since this procedure is performed in a single step, leading to less morbidity, it is more technically easier and economically affordable, but not inferior to MACI and ACI, which benefits both patient and surgeon.

Some studies published good short to mid-term results following primary arthroscopy-AMIC (AT-AMIC), with similar functional scores compared to previously described open techniques. The idea of AT-AMIC is to avoid malleolar osteotomy, leading to an even less morbid procedure. Some studies have already demonstrated the technique and mid-term follow-up with good results. At least three systematic reviews further showed improvement in functional and pain outcomes, with one also showing imaging improvements[13,14,15]. The indication to perform this procedure encompasses lesions smaller than 2 cm^2 with or without fail of the subchondral bone (Figure 3).

Autologous matrix-induced chondrogenesis and arthroscopy-autologous matrix-induced chondrogenesis with biological scaffold

Cartilage regeneration keeps posing many difficulties in its treatment due to previously described conditions. Yet, even with the debated limitations, autologous chondrocytes continue to be widely applied. In this context, mesenchymal cells are gaining space as a superior alternative for tissue regeneration due to their high capacity for proliferation, differentiation and for the large sources of mesenchymal cells. However, an inconvenience is that facilities and technical expertise are required, which are not accessible in many locations[16]. Given that, bone marrow mononuclear cells (BMMCs) and platelet rich fibrin (PRF) are some examples of what is called a "biologic scaffold" showing promising results around regenerative cartilage field, with lesser cost and easy technique.

Platelet rich fibrin is a second-generation platelet concentrate that contains many growth factors stored in platelet granules and other cells, constituting a type of "supermembrane," which can also be mixed with chopped autologous cartilage that was collected from the talar lesion itself but can also be considered a fibrin biomaterial, as it serves as a matrix for the migration and proliferation of fibroblasts and endothelial cells[17,18]. There is a lack of studies acknowledging the use of this technique on osteochondral lesions, but it is reasonable to start thinking about adopting it due to its safety, relatively low cost, and promising results.

A recent paper conducted by Balta and Kurnaz analyzed histologically and macroscopically the formed cartilage in rabbits after biological adjuvants (PRF) individually and in combination, showing statistical differences in favor of the first group against the control, especially when used in combination[19]. Tafiuk et al. showed an effective regeneration of cartilage defects after a surgical treatment integrating microfracture (MFx), synovial grafts, and PRF membranes[20]. Further, Wong et al., after developing a one-stage method that combined PRF and autologous cartilage autografts, reported a relatively complete cartilage repair[21]. Hence, the literature shows that besides having great regenerative capacities, PRF and other biological materials can be combined with other techniques that potentialize its results. This technique can also be performed with malleolar osteotomy or through arthroscopy approach.

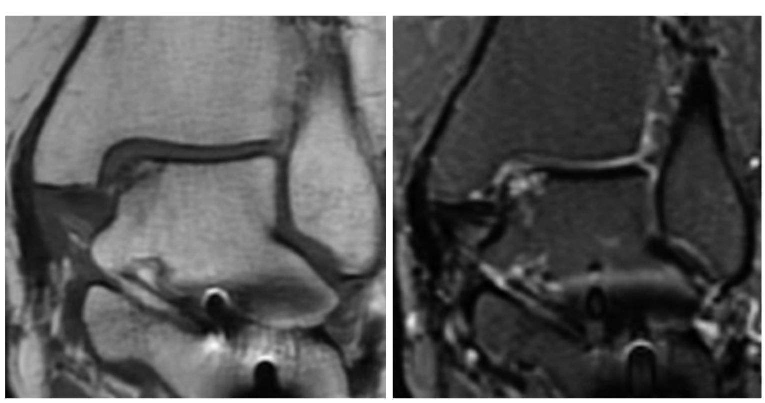

Figure 2. Magnetic resonance images (left-hand T1 and right-hand T2) of a patient with osteochondral lesions of the talus treated through microfractures that progressed unsatisfactorily after eight months.

The technique used by them follows these steps (Figure 4):

- OLT debridement and regularization (open or arthroscopically)
- Cancellous autograft from the ipsilateral calcaneus to fill the defect
- Lesion sealing with biological scaffold (PRF membrane)
- Fixation with fibrin glue

The biological scaffold preparation follows the Choukroun process and centrifugation[22] (Figure 5). The generated fibrin clot is mixed with the minced cartilage from the talus and then prepared to cover the cartilage defect (Figure 6).

Direct cartilage repair strategies: Microfractures and retrograde drilling

These techniques include bone marrow stimulation (microfracture) and retrograde drilling, where perforations on the subchondral bone are performed, allowing the infiltration of bone marrow progenitor cells and the formation of fibrocartilage within the defect. As it is composed primarily of Type I collagen, rather than Type II, which composes most hyaline cartilages, it has inferior biomechanical and structural properties than the natural one[23]. Besides that, they produce good clinical outcomes that remain for at least four years.

A point to note regarding the successful outcome of these techniques is the size of the OLT site once they inversely correlate to each other. In a study analyzing 105 OLT treated arthroscopically, debridement, and microfracture, the lesion size was determinant for the procedure's success, whereas the cutoff area, determined through MRI in another study, is 1.2 cm^2[24]. In addition, other factors lead to less improvement, such as the lesion time, presence of arthritis and underlying cysts, and when there is an uncontained lesion.

In recent years, these strategies have been abandoned in multiple centers worldwide due to deterioration of the initial good results, favoring regenerative methods, even for mild cases.

Cartilage replacement strategies: Osteochondral autograft transfer, osteochondral allograft, and particulate juvenile cartilage allograft transplantation

All these three techniques describe the substitution of the lesioned cartilage for another healthy one from different sources—osteochondral autograft transfer (OAT): harvested cartilage from talus or non-weight bearing area of the knee (mosaicplasty) (Figure 6); Osteochondral allograft: harvested from human cadavers; particulate juvenile cartilage allograft transplantation (PJCAT): particulate juvenile cartilage from deceased donors up to 13-years old (Figure 7).

They are often indicated for big lesions (1 – 1,5 cm^2, or even bigger ones), talar shoulder, or unstable rim of the surrounding cartilage**.**

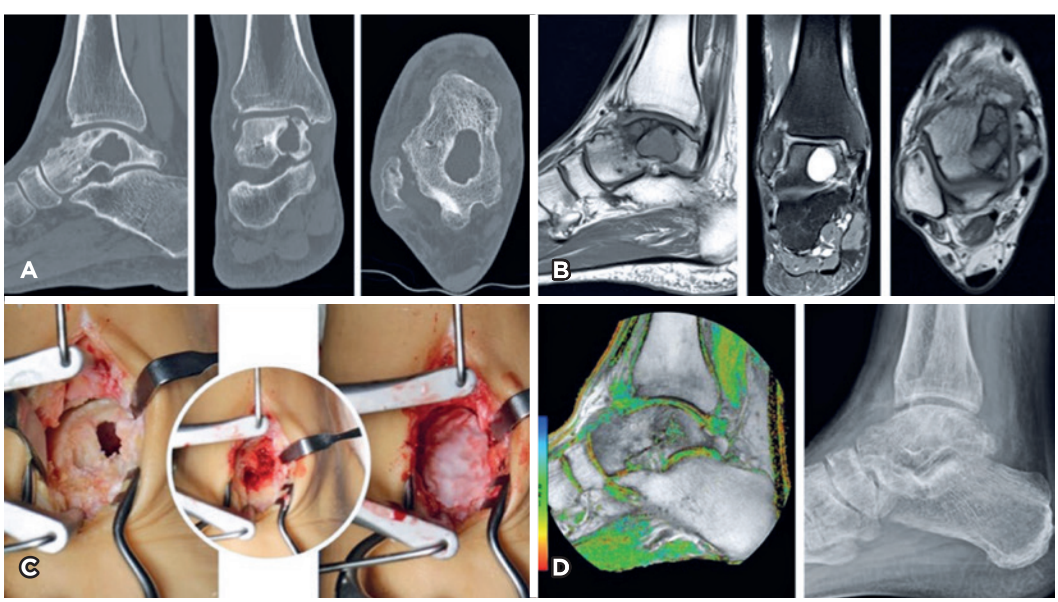

Figure 3. Autologous matrix-induced chondrogenesis (open) in severe osteochondral lesions of the talus with giant cysts: A. Computed tomography images (Sag, Cor, Trans); B. Images (SagT1, CorT2, TransT1); C. Through an anteromedial longitudinal incision and with a pin distractor, the area of the lesion is exposed and the "entrance" of the cystic lesion identified; The lesion is curetted and cleaned, being filled with an autologous cancellous bone graft and then covered with a chondroinductive membrane that is fixed to the bed with fibrin glue; D. T2 map (sagittal) and plain radiograph of the ankle (lateral) showing integration of the membrane into the bed; note the recovery of the tibiotalar joint space on the lateral radiograph.

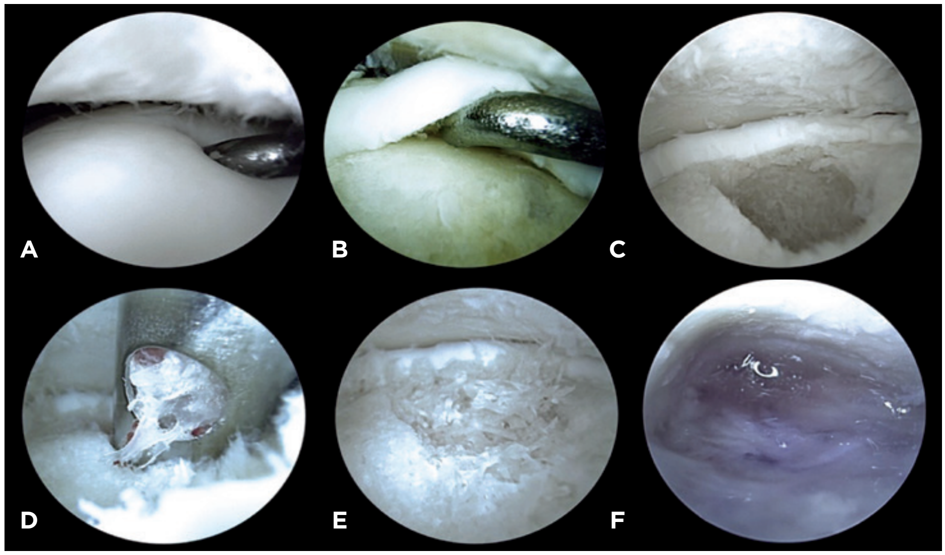

Figure 4. Arthroscopy-autologous matrix-induced chondrogenesis: Arthroscopic images of the procedure performed on the patient shown in Figure 1: A. Identifying the location of the articular cartilage fissure; B. With the probe placed at the cartilage-bone transition, one can identify the limits of the osteochondral lesions of the talus; C. Once all the unstable cartilage has been removed, we debride the subchondral cyst; D. Fenestrated cannula containing autologous cancellous bone that will be impacted into the cyst to create a support base for the chondroinductive membrane; E. Cyst-filled up with cancellous bone to the level of the original subchondral bone of the injured area; F. Covering the lesion with the membrane and fixing it with fibrin glue. Note: The surgical steps in images D, E, and F are performed in "dry arthroscopy mode," as joint irrigation is interrupted to guarantee the integrity of the tissues that fill and cover the lesion.

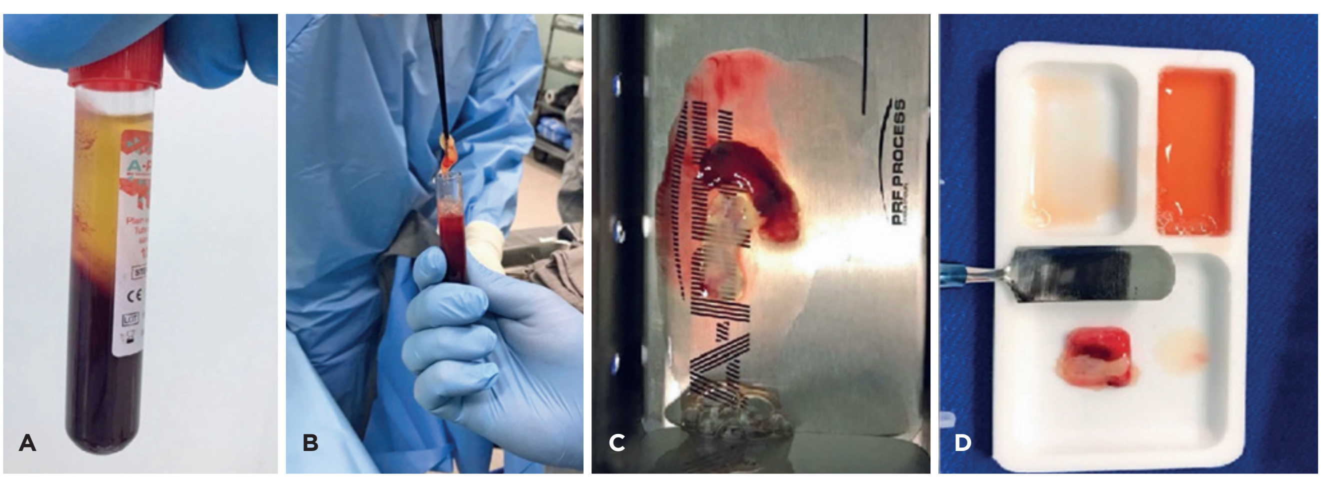

Figure 5. Platelet rich fibrin membrane collection and handling procedure. A: material after centrifugation, with a fibrin clot in the central portion. B: Fibrin clot removal. C and D: modeling process of the platelet rich fibrin collected material.

These techniques are less frequently performed due to ethical concerns, among other questions: donor site morbidity, thickness and curvature differences between knee and talus, and tissue incompatibility. However, short- and mid-term results have been published with promising outcomes in 87%–94% of the cases[25]. In a systematic review, a success rate of 77% was found after autograft transplantation for primary lesions and 90% for secondary lesions[26]. Further, Migliorini et al.[27] found fewer rates of failure and revisions after autograft at mild-term follow-up compared to allograft.

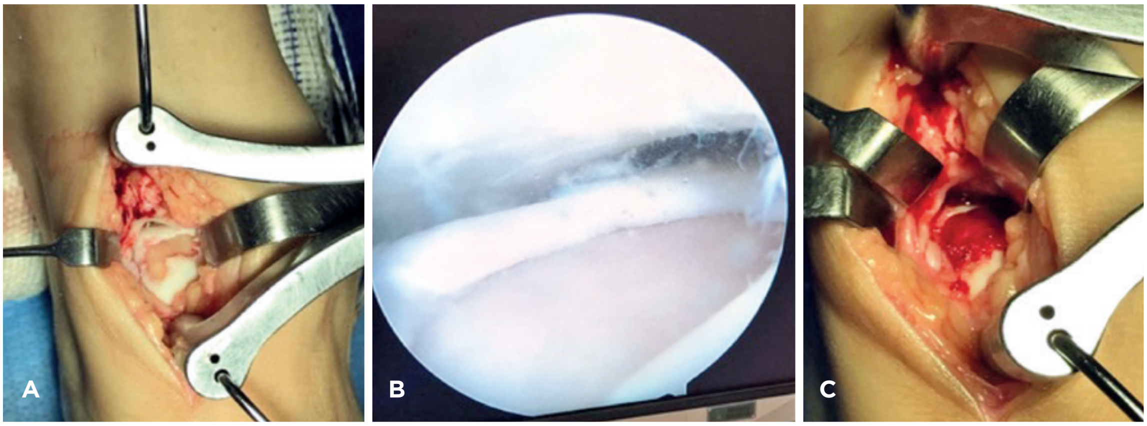

Figure 6. Osteochondral lesions of the talus under direct view after distraction (A) and during arthroscopy (B). Talus lesion covered by collected platelet rich fibrin membrane (C).

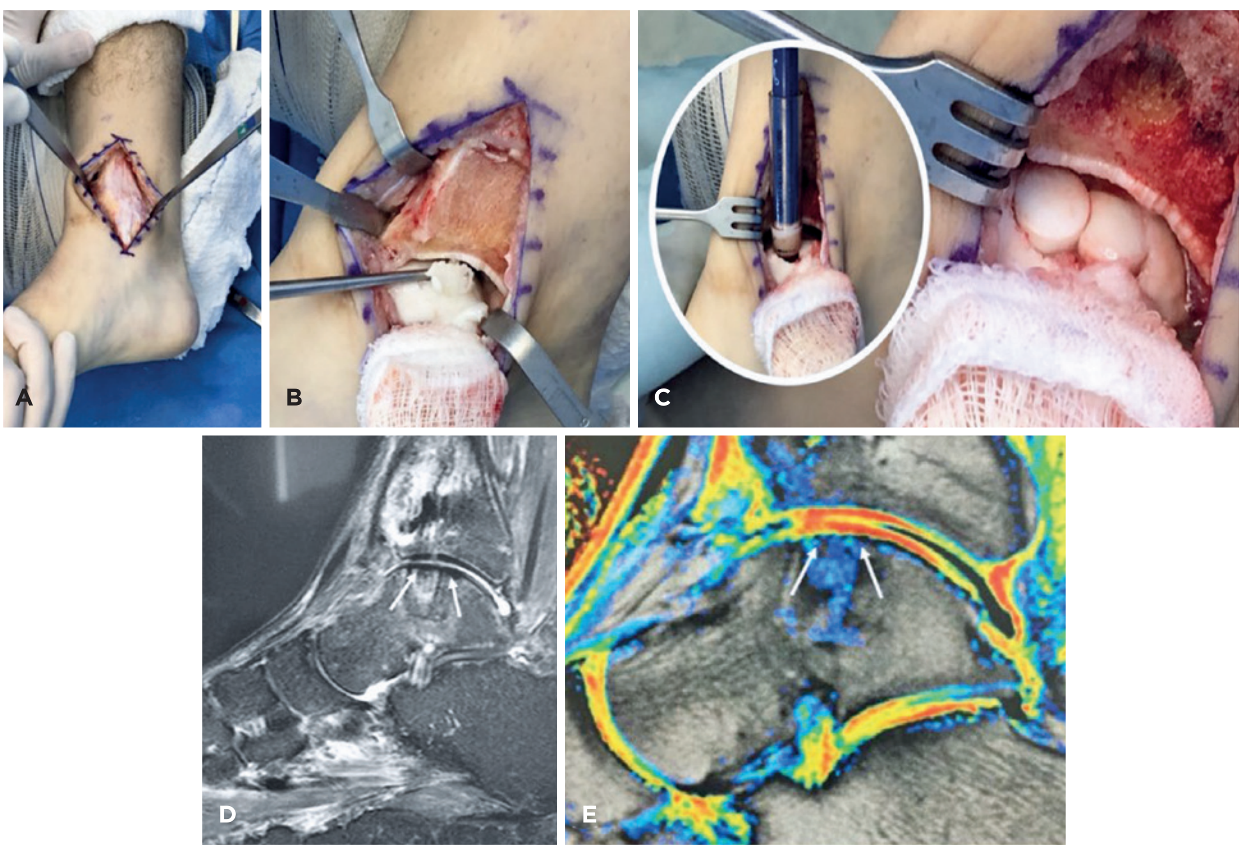

Figure 7. Osteochondral autologous transplantation: A. Medial surgical incision; B. Through a slightly oblique osteotomy that starts from the medial metaphyseal region of the tibia towards the "armpit" of the tibia, the osteochondral lesions of the talus is exposed; C. Using a set of trephines, the bed of the recipient area is prepared, and the osteochondral cylinders are removed from the donor area to be introduced sequentially into the recipient area. It is important to try to leave as little space as possible on the joint surface without cartilaginous coverage, which can be achieved by overlapping the cylinders; D. Sagittal T2 image showing the integration of the implanted osteochondral cylinders into the body of the talus. Arrows point to the completely restored cartilaginous layer and subchondral bone; E. T2 map showing the signal of the cartilage in the repaired area (arrows), which is equivalent to the signal of the normal cartilage of the distal tibia that can be seen just above (reddish-orange color in this exam).

How to approach an osteochondral lesion

The approach to each osteochondral lesion is related to the technique that will be performed and the location of the lesion.

When a mosaicplasty (OAT) is indicated, this procedure can only be performed through malleolar osteotomy (Figure 7A and B), but AMIC, ACI, and microfractures, can be performed minimally invasive (arthroscopy or mini-arthrotomy) or through malleolar osteotomy.

Arthroscopy advantage

As new surgical options for OLT evolved over the years, the arthroscopic approach has become the gold standard for these lesions. However, many surgeons face the dilemma of approaching central, combined, and posterior lesions.

Nowadays, anterior, central, and central-anterior lesions are easily treated arthroscopically, with the ankle in plantar flexion and noninvasive distraction. For central, posterior, and central-posterior lesions, the use of Hintermann's spreader (static distraction) applied laterally or medially with the ankle in plantar flexion allows visualization to more than 80% of the talus, being a successful strategy to treat these lesions through arthroscopy, using membranes to cover the defect.

Malleolar osteotomy

Due to its central position in the hindfoot and embedded in the tibiofibular clamp, surgical access to the talus is difficult. As stated previously, OLT can occur either on the posterior aspect of this bone, which makes this condition even harder to treat; thus, lateral and medial malleolar osteotomy can be performed to gain optimal accessibility whenever an arthroscopic approach is not possible. However, once the main treatment concern about this condition is to achieve optimal and fast functional recovery to daily and sports activities, an osteotomy may enhance complications, delay weight-bearing, and return to daily activities[28].

Despite the concern about the more invasive nature of the malleolar osteotomy compared to the arthroscopic approach, some studies have already shown its safety and good short- to mid-term functional and imaging results. Sadlik et al. showed similar AOFAS and magnetic resonance observation of cartilage repair tissue (MOCART) scores after osteotomy and arthroscopy[29]. In a multicenter study, Pardiolleau et al. found no specific complications associated with malleolar osteotomy[28]. However, Leumann et al. showed no short to mid-term morbidity but little long-term morbidity and the necessity of many re-interventions for implant removal[30].

Mini access (anteromedial and anterolateral) to avoid malleolar osteotomy

Even though most OLTs can be treated arthroscopically, when it comes to larger defects, a former arthrotomy may be required for better visualization and proper access. Most of the time, arthrotomy is achieved through the malleolar osteotomy, but some distractions using a static spreader (Hintermann's spreader) allow 90% visualization of talar cartilage, decreasing the indication of malleolar osteotomy (Figure 3C).

Final considerations

Even though there are many possibilities to treat this important orthopedic condition, with good promising results in cartilage restoration, fast return to daily and sports activities, and functional outcomes, there is a lack of well-conducted comparative studies or randomized controlled trials that support these techniques. Despite that, we can see

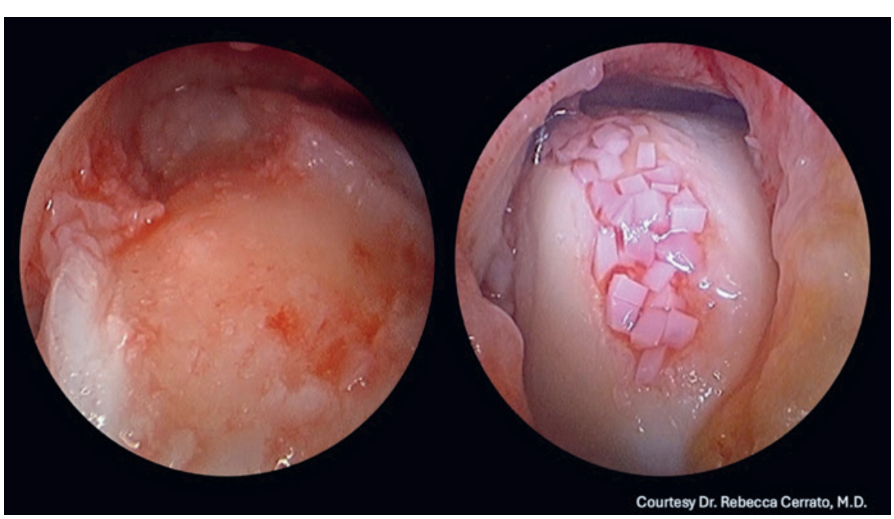

Figure 8. Particulate juvenile cartilage allograft transplantation (Courtesy of Dr. Rebecca Cerrato, MD)

an increasing tendency to adopt advanced techniques that aim at cartilage regeneration and replacement, especially for increased lesion sizes, rather than reparative ones. For example, a biologic scaffold consisting of autologous tissue, technically easy to conduct and financially affordable, might be a great option to treat OLTs, together with other regenerative strategies.

The surgical technique-surgical approach and managing strategy should be primarily selected depending on the status of the overlying cartilage, lesion size, presence of subchondral cists (size and number), and OLT containment.

Further common underlying causes are chronic lateral or medial ligamentous ankle instability and hindfoot malalignment in either isolation or combination, which must be treated simultaneously. Without addressing these pathologies, the likelihood of poor results or failures appears much higher.

Although the outcomes of most of these techniques are encouraging, it is impossible to recommend one procedure over another due to a lack of comparative analyses. Consequently, treatment should be individualized for every patient, with appropriate counseling regarding outcomes and associated pros and cons of the recommended technique.

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Special Article

Progressive collapsing foot deformity: how to use new knowledge in developing countries

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Abstract

The 2019 progressive collapsing foot deformity (PCFD) consensus did not only change the disease nomenclature and provided a new classification for the condition formerly known as flatfoot deformity. It was also the pinnacle of a revolution in the field in terms of knowledge and clinical perspectives. The use of advanced imaging, such as weight-bearing computed tomography, three-dimensional algorithms, and magnetic resonance, expanded the way we understand peritalar subluxation and how we can address it. However, much of these improvements felt short in terms of global reproducibility due to economic restraints. The objective of this review study is to present PCFD new concepts through the lens and realities of developing countries, considering their potentially limited access to novel technologies.

Level of Evidence V; Expert opinion.

Keywords: Flatfoot; Tomography; Cone-Beam Computed Tomography; Disruptive Technology; Low Cost Technology; Developing Countries.

Introduction

Progressive collapsing foot deformity (PCFD) was the name chosen to better describe what was previously termed flatfoot by a consensus of world specialists in the disease through a series of articles, in 2020[1,2]. The nomenclature would solve some of the problems associated with adult acquired flatfoot deformity, such as the fact it might occur outside the adult scope and present congenital features, besides not being a variation of normality[1,3,4]. Setting these concepts and establishing the posterior tibial tendon acquitting as the main driver of the disease was only possible due to an ocean of knowledge produced in the years previous to the consensus[5,6]. What was produced in the following years substantiated and expanded these principles around PCFD[7,8], and much of this new knowledge was possible with the advent of the weight-bearing computed tomography (WBCT)[9,10]. By assessing the foot and ankle under physiological stress, relations among structures and their environment were redefined due to this clearer portray of the local anatomy, including coronal and three-dimensional (3D) assessments[11-13]. This technology allowed further development of bone segmentation and 3D mappings, increasing our understanding on how components interact in the normal and PCFD scenarios[14,15]. Lately, the clinical applicability of these findings has been putted into test, and results are encouraging[16].

Contrary to what is expected from a scientific product, many of the treatment plans elaborated were not able to reach practice globally, especially in developing countries with economic restraints. This review study aims to report the scientific advancements made in PCFD over the last years while trying to implement these ideas in locations with limited access to technology.

Study performed at the Medstar Orthopedic Institute, MedStar Union Memorial Hospital, Baltimore, United States.

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The Concept of Peritalar Subluxation (PTS)

The concept is not new, being introduced by Sangeorzan et al. more than two decades ago and using conventional weight-bearing radiographs (WBRs) and non-weightbearing computed tomography (CT)[5,17,]. In PCFD/flatfoot, the talus would stay in a fixed position while the structures around it would progressively subluxate, moving in external rotation, eversion, and dorsiflexion (Figure 1)[6]. Although intuitively being an ongoing aspect of a pathological process, PTS was also found to be extremely accurate in diagnosing PCFD, also being reliable for assessment of treatment success[16,18].

Ananthakrisnan et al. used the overlap of posterior facets of the talus and calcaneus as a marker of PTS to demonstrate the difference between flatfeet and controls (0.92 vs. 0.68; p = 0.0066)[17]. Later, de Cesar et al. explored the middle facet of the subtalar joint and found this subluxation has a high accuracy (>17.9%, with 100% specificity and 96.7% sensitivity; AUC = 0.99) and presents as an earlier mark (middle vs. posterior difference: 17.7%) for PCFD diagnosis (Figure 2)[18,19]. Whilst most of these findings were established by WBCT, which could be of limited access in developing countries, concepts can still be appreciated in simulated WBCT and WBR[20,21].

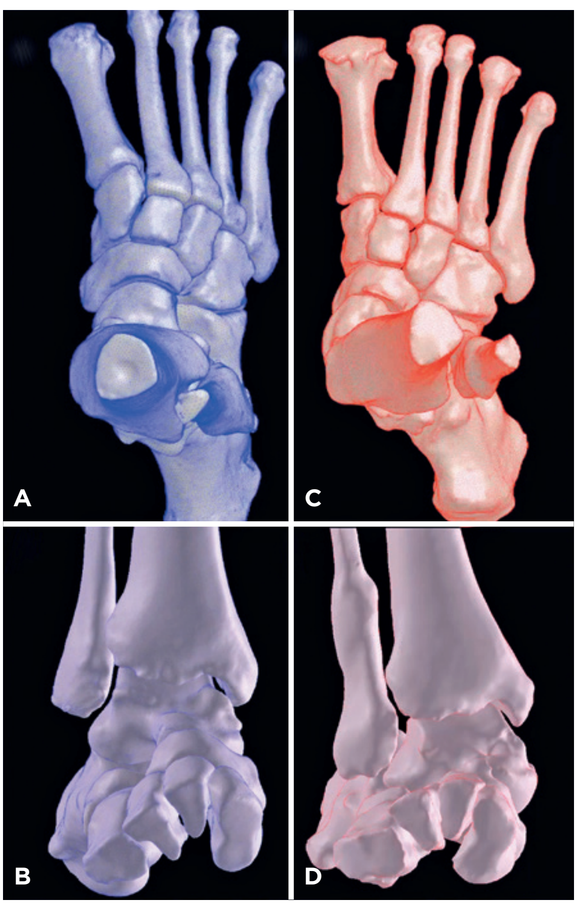

Figure 1. Three-dimensional weight-bearing computed tomography reconstruction from a patient with neutral/physiological alignment (blue; A and B) and progressive collapsing foot deformity (red; C and D). Axial (A and C) and coronal (B and D) views show signs of peritalar subluxation, such as external rotation and eversion of the subtalar joint, midtarsal external rotation and translation, and subtalar and subfibular impingement.

Sinus tarsi impingement (STI) and subfibular impingement (SFI) are also important clinical and radiographic manifestations of PTS[14,22]. They probably represent prognostic factors too, STI being a sign of symptom onset and SFI, an indication of more pronounced and advanced PTS[16]. Several studies demonstrated a correlation between impingement and PCFD diagnosis, function, pain, deformity severity, and soft tissue impairment[15,16,22,23]. Recognizing an STI or SFI in the clinical setting is crucial and does not require advanced imaging[23,24]. Physical examination and conventional WBR, including a hindfoot alignment view, are adequate and inexpensive[25,26].

It is important to differentiate STI from subtalar arthritis, since they can determine distinct treatments (joint sparing vs. fusion)[27-29]. In STI, alongside with localized pain at the sinus tarsi, radiographs show a direct contact between the lateral process of the talus and the Gissane angle in the calcaneus[22]. If available, a magnetic resonance imaging can show indirect signs, such as bone edema, subchondral cysts, or erosion of the lateral process and Gissane[23]. Arthritis has a more diffuse clinical pattern and also significant loss of subtalar joint space,

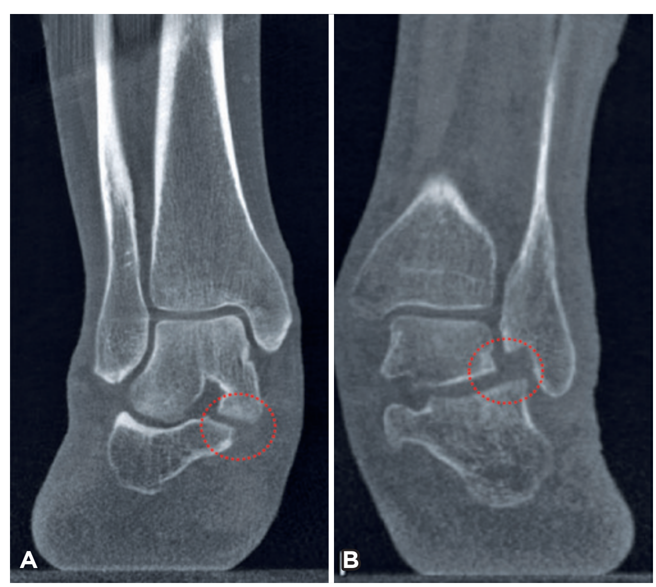

Figure 2. Coronal weight-bearing computed tomography images showing middle facet subluxation (A) and posterior facet subluxation (B) in patients with progressive collapsing foot deformity. The red circle highlights the area of interest and where the subluxation is measured.

which might be not so easy to assess with the overlapping of bones (Figure 3)[24,30]. A combination of diagnostic modalities might provide answers in challenging cases[4,28].

Weight-bearing Computed Tomography (WBCT)

The development of WBCT changed the PCFD understanding substantially[21]. Not only PTS and joint interaction became clearer, but other aspects of the disease were also highlighted[1,11,31]. The new consensus classification incorporated the idea of different deformity patterns combining into a PCFD presentation (Table 1)[1,32]. Much of the classes are easily recognizable clinically and radiographically, such as A (hindfoot valgus) and E (ankle instability). However, as previously stated, class D (PTS) is better appreciated by WBCT[31]. The identification of classes B (midfoot abduction) and C (medial column instability), in particular, can be incremented with the technology due to its multiplane capability[31]. Instability of the tarsometatatarsal or naviculocuneiform joints, in the form of plantar gapping, dorsal subluxation, or arthritis, can change the therapeutic approach of PCFD[33-35]. Foot tripod reestablishment through a medial longitudinal arch stabilization procedure directed to the apex of the deformity is a fundamental step of the reconstruction plan[36-38]. Again, the rational use of a careful clinical assessment combined with WBR (and, eventually, simulated WBCT) to assess classes B and C can bring plentiful information for the decision making[39,40].

Multiple imaging acquisition by WBCT also allowed the development of different software to analyze the obtained data[20,41,42]. One of the first and most impactful of these is the Foot and Ankle Offset (FAO)[43]. The 3D relation between the center of the ankle and the foot tripod was introduced by Lintz et al. with the use of WBR, at first[44]. The Torque Ankle Lever Arm System (TALAS®; CurveBeam™, LLC, Warrington,

Figure 3. Progressive collapsing foot deformity patient with sinus tarsi impingement. Lateral weight-bearing radiograph (A) shows the lateral facet of the talus touching the crucial angle of Gissane in the calcaneus. Assessment of the joint space is significantly hindered by the apposition of bones. The technique illustrates the contact between bones as well as cystic changes (B) and sclerosis secondary to the impingement. Other indirect signs of STI can be seen in the magnetic resonance imaging, such as bone edema, subchondral cysts, and local synovitis (D).

Table 1. Progressive collapsing foot deformity consensus classification enabling a combination of classes with flexible (stage I) or rigid (stage II) presentations

Types	Stage I: Flexible Deformity type/location	Stage II: Rigid Consistent clinical/radiographic findings
Class A	Hindfoot valgus	Hindfoot valgus alignment Increased HMA, HAA, and FAO
Class B	Midfoot/forefoot abduction	Decreased talar head coverage Increased TNCA Presence of STI
Class C	Forefoot varus/medial column instability	Increased TFMA Plantar gapping at first TMT/NC joints Clinical forefoot varus
Class D	Peritalar subluxation/dislocation	Significant subtalar joint subluxation SFI
Class E	Ankle instability	Valgus tilting of the ankle

HMA: hindfoot moment arm; HAA: hindfoot alignment angle; FAO: foot and ankle offset; TNCA: talonavicular coverage angle; STI: sinus tarsi impingement; TFMA: talus-first metatarsal angle; TMT: tarsometatarsal joint; NC: naviculocuneiform joint; SFI: subfibular impingement.

PA) program allowed FAO to be obtained in a semi-automatic manner, by clicking at the most distal voxel (aspect) of the first metatarsal head, followed by the most distal voxel of the fifth metatarsal head and the most distal voxel of the calcaneus posterior tuberosity[45,46]. Those three points generate the foot tripod[44,46]. Finally, the most central point of the talar body is obtained and the amount of this point deviation considering the center of the tripod is automatically measured by a percentage (Figure 4)[47]. Normal values range between -0.6% and 5.2% (mean: 2.3%), as positive values above 5.2% indicate valgus, and negative values below -0.6%, varus[45,46]. The FAO has been demonstrating high reliability rates (>0.97), diagnostic values (>4.6%: 100% specificity and 89.2% sensitivity), and clinical correlations as a surrogate for overall foot and ankle alignment[13,48-50]. Manual measurement using simulated WBCT or even WBR is possible in situations where a WBCT or the software are not available (Figure 4)[44-46].

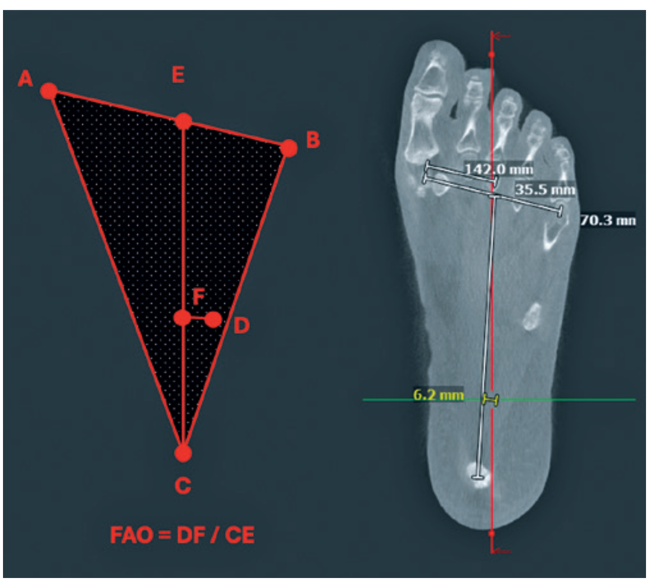

Figure 4. Measuring the foot and ankle offset without semi-automatic software. In this case, a conventional computed tomography with simulated weightbearing was used. The most distal aspect of the first metatarsal is determined in the three computed tomography planes and marked (point A). Using the three planes, the most distal aspect of the fifth metatarsal is obtained (point B). Next, the most distal aspect of the calcaneus is found (point C). The mid-distance between points A and B (70/2 = 35) is marked as point E. A line is drawn between points E and C and the distance is measured (142 mm). The projection of the center of the talus to the tripod plane is established as point D. A perpendicular line connecting point D with the CE line (point F at the line) represents the DF distance (6.2 mm). Line F would be a perfect alignment of the talus over the center of the tripod. The FAO can be obtained by dividing DF (6.2) by CE (142); in the represented case, 0.0436, or 4.36%, of talar deviation from the point F or the central tripod line.

South America currently holds only two WBCT equipment in operation, while it is still scarce in Africa and Asia. Nonetheless, much of the PCFD concepts developed or expanded with WBCT have strong clinical and radiographic correspondence[20]. Classes, stages, and presentations can be clearly identified using traditional approaches. As many of the ideas and advancements brought by these apparatuses, FAO can be employed with creativity, using the concepts introduced by the original authors.

Three-dimensional (3D) Algorithms

Segmentation is not a novelty when it comes to imaging assessment and medical applications[51,52]. Image acquisition and software developments were fundamental to the thriving of this technology, allowing 3D WBCT mapping algorithms to be established[53,54]. The software captures the images from the WBCT file, creating a 3D isosurface of the bone tissue[55]. In order to obtain a patient-specific shape, deformable shape models are used by the program, which also automatically generates landmarks and bone axis[56]. Bone segmentation can then be used to perform simple, automatic angular and linear measurements reliably (ICCs: >0.972) and faster (97%)[53,57]. Mostly, a more comprehensive assessment of structural interaction in a 3D approach is possible using distance and coverage mapping[15,56.58].

Many of the PCFD concepts proposed in the last decades were substantiated using this advanced technology[58,59]. Studies were able to fully characterize PTS through changes on joint coverage, bone positioning, and distancing[57,60]. Middle facet subluxation (46.6% of uncoverage), sinus tarsi impingement (98% increase in coverage), and subfibular impingement (17 of 20 patients) were more objectively and extensively appreciated using maps of coverage and distance for the specific areas[15]. A direct clinical application of the same concepts was later demonstrated by de Cesar et al. when showing changes in coverage and distance by 3D mapping in patients operated for PCFD joint-sparing procedures (Figure 5)[16]. A direct correlation among improvement in patient reported outcomes (PROs), improvement in facet coverage (middle facet and PCS; $p = 0.030$), and impingement (SFI and PROMIS; $p = 0.020$) was established. In this study, the FAO improvement also affected PROs significantly (i.e., $R^2 = 0.35$ for VAS), showing that the correction of overall alignment, joint coverage, and extra-articular impingements (STI and SFI) have a positive effect on clinical results.

Although challenging to be obtained in low economic environments, 3D WBCT mapping algorithm conceptions help not only by driving innovation in the field, but also allows a more contemplative metric[16,59]. Many of the software being developed for segmentation and 3D analysis are able to get data from simulated WBCT and, in some extent, WBR. Imaging from normal, pathological, and cadaveric samples are feeding artificial neural networks that might be able to translate data from different modalities. As the orthopedic industry evolves and invests in this technology, more are the chances of these software being offered freely to providers around the globe.

Surgical Planning and Interventions

Application of basic concepts in segmentation and 3D WBCT algorithms allowed researchers and engineers to develop surgical planning tools in programs[(61-63)]. It is possible to feed the software with preoperative WBCT images and simulate the effect of isolated or combined osteotomies on specific measurements and on the overall foot alignment (Figure 6)[(64-66)]. As discussed, artificial intelligence is supplied with cases and studies, making 3D preoperative plans increasingly more consistent[(63,67)]. Although this technology will not replace the surgeon's insights and experience, it will potentially add good information when making intraoperative decisions, such as the desired amount of displacement in a calcaneal osteotomy, the size of an wedge for a midfoot osteotomy, or the need for additional soft tissue procedures[(63,67)]. Again, these are not indispensable steps when planning PCFD reconstruction, but there is hope that these software become widely available in the future, with the ability to translate data from simulated WBCT and WBR[(68)].

Technical surgical aspects have not changed much in the last decades, even though advancements in soft tissue reconstruction are promising[(69,70)]. There is a tendency of leaving the posterior tibial tendon intact whenever possible[(23,71,72)]. Placing the calcaneus under the tibial axis and reestablishing the foot tripod are still the main goals of PCFD bone reconstruction, while avoiding hypercorrection[(4,28,37,73)]. The importance of the first ray and medial column in regaining triple foot support has been highlighted in the last years (Figure 7)[(24,34-36)]. A short or insufficiently plantarflexed first ray/medial column might not be enough to derotate the hindfoot, helping to correct PTS[(74,75)]. On the other spectrum of the disease – rigid deformities –, well-aligned triple arthrodesis is still found to be mandatory for good outcomes and to protect the ankle joint[(39,76)]. Moreover, as total ankle replacements continue to evolve, they became a viable option when treating class E deformities in a PCFD setting[(77,78)].

New implants are constantly developed to treat the different aspects and presentations of PCFD. Still, they lack clinical superiority over the traditional implants available in developing places[(79-81)]. Allograft pre-molded wedges can be substituted by metal or autograft[(81)]. Free tendon graft or suture material might replace expensive suture tapes and anchors[(77,78,82,83)]. The creativity of the developing world surgeon in specific situations is also an important factor when operating specific cases.

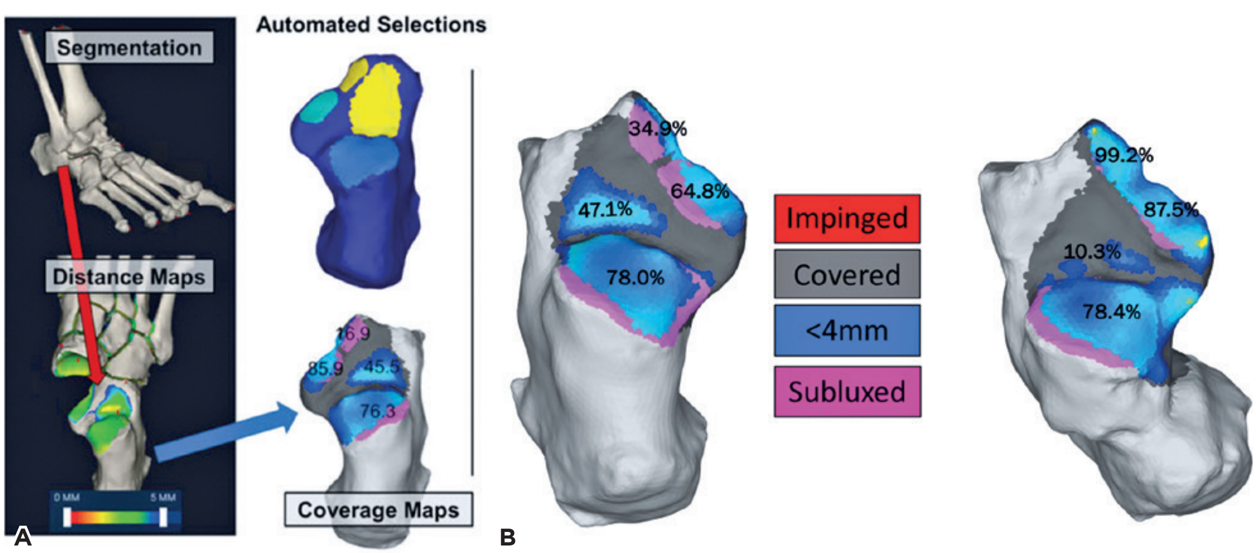

Figure 5. Three-dimensional weight-bearing computed tomography algorithms starts with bone segmentation (A), providing anatomical displays of the desired interaction – in this case, the subtalar joint. Vertical vectors between talus and calcaneus are obtained, portraying distance and coverage maps. Distance is portrayed in millimeters, red colors representing areas with smaller distances (arthritis or impingement) and green/blue, greater distances. Coverage is displayed using color diagrams for these vectors that characterize how much the structures are close to or with no contact with each other. Red represents contact between bones (impingement), blue symbolizes distances bellow 4 mm (physiological coverage), gray denotes coverage with distances over 4 mm, and pink indicates no coverage (subluxation). Example of a Three-dimensional weight-bearing computed tomography coverage map (B) in progressive collapsing foot deformity preoperatively and postoperatively. Before surgery, sinus tarsi have signs of impingement (more coverage: 47%, less distance) and medial and anterior facets have a significant subluxation (34% and 64% of coverage, respectively). After joint-sparing procedures, facets recover much of the coverage (99% and 87%) and sinus tarsi impingement is considerably improved (10%).

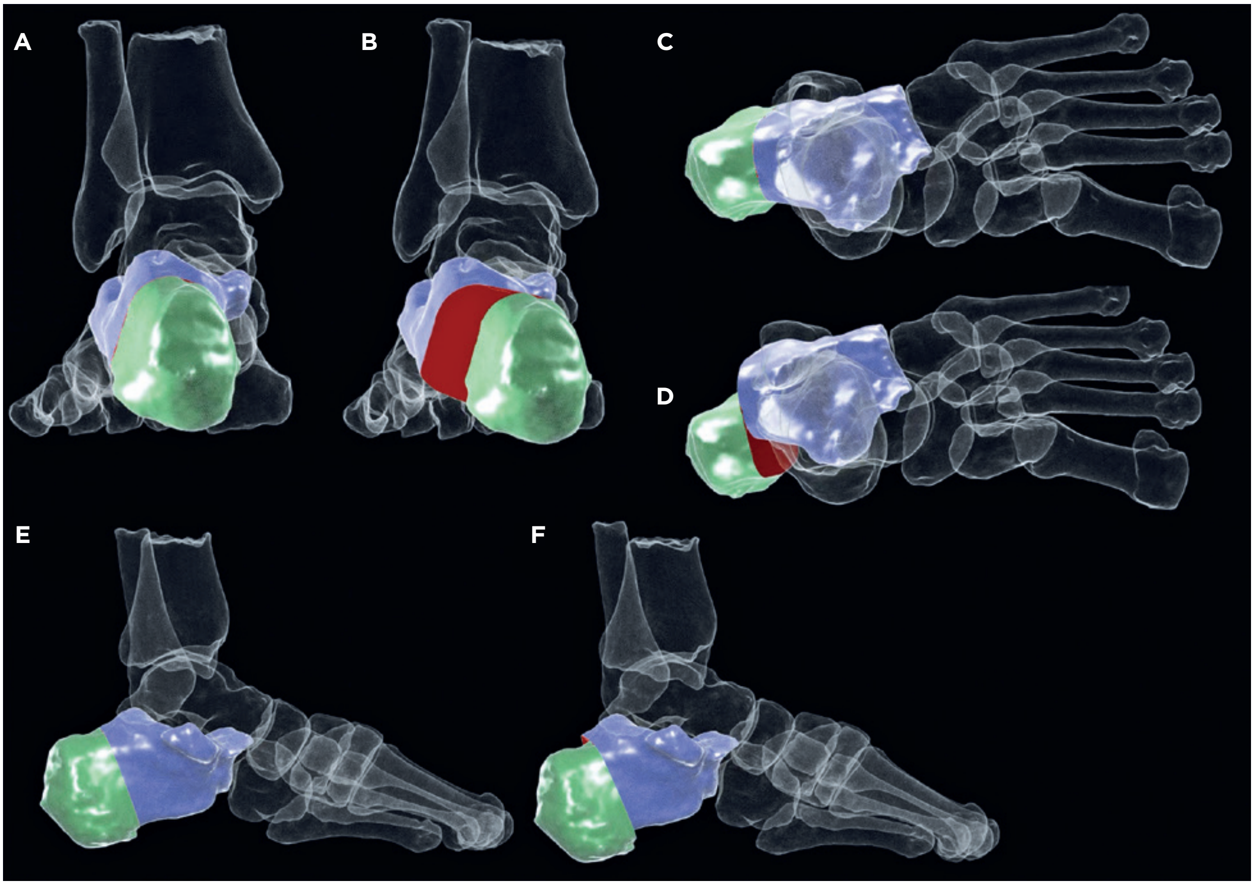

Figure 6. Example of preoperative planning of a medial displacement calcaneal osteotomy in a progressive collapsing foot deformity. Coronal (A; B), axial (C; D), and sagittal (E; F) reconstruction images comparing the overall alignment and specific angular and metric relations between bones. Semi-automatic angles can be easily measured in preoperative and postoperative assessments. Even an isolated hindfoot osteotomy can affect different aspects and areas of the foot and ankle.

Figure 7. Example of a progressive collapsing foot deformity patient classified as 1ABC presenting with significant posterior tibial tendon degeneration and a viable muscle unit that underwent surgical treatment. Preoperatively (A), sinus tarsi impingement, talonavicular uncoverage, and first tarsometatarsal joint instability are noted. At the two-year follow-up visit (B), after a 10 mm medial displacement calcaneal osteotomy, a 10 mm Lapicotton, posterior tibial tendon reconstruction using hamstring allograft, and a gastrocnemius recession. The capability of the first ray to derotate the hindfoot and correct the talonavicular uncoverage (midfoot abduction) is appreciated.

Conclusions

Scientific advancements drive humanity. Health sciences are not different, due to our continuous search to offer our patients the best treatment. Substantial information produced in the last decades was detrimental to the development of PCFD understanding. Technology has provided us with expanded perceptions on how the disease behaves and presents itself. Impact on treatment is also starting to be shown. Although much of these methods are not available in developing countries, concepts and produced data can be applied in clinical practice using existing and resourceful tools. Knowledge will always be the most reliable instrument in the hands of a surgeon and knowledge has no geographical or financial background.

Authors' contributions: Each author contributed individually and significantly to the development of this article: NSBM *(https://orcid.org/0000-0003-1067-727X) Conceived and planned the activity that led to the study, wrote the article, participated in the review process; KD *(https://orcid.org/0000-0002-8061-4453), and CCN *(https://orcid.org/0000-0001-6037-0685) Bibliographic review, participated in the review process. All authors read and approved the final manuscript.*ORCID (Open Researcher and Contributor ID) iD.

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Systematic Review

Idiopathic toe walking: What's New? An Integrative Review

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Abstract

Objective: Consolidate the current knowledge on idiopathic toe walking, provide a critical overview, and identify areas for potential future research.

Methods: An electronic search was conducted in the following databases up to June 2023: MEDLINE, EBSCO, Embase, CINAHL Plus, and PubMed. The PICO framework was employed to define search terms.

Results: Despite considerable methodological heterogeneity among studies, a stronger inclination was found to investigate etiological and prognostic factors. There is a trend for a higher prevalence in boys with a positive family history. Novel classifications have been proposed to improve differential diagnosis. Among conservative treatment options, there is stronger evidence for gait improvement using serial casting followed by orthoses. Severe cases may benefit from surgical zone III gastrocsoleus lengthening.

Conclusion: Further studies with standardized methodologies are required to clarify questions about this condition's etiology, classification, and treatment. Nonetheless, there is a higher level of evidence supporting conservative treatments with serial casting and orthoses and zone III gastrocsoleus lengthening for severe cases in the second decade of life.

Level of evidence II; Diagnostic studies.

Keywords: Walking; Equinus Deformity; Foot; Treatment.

Introduction

Idiopathic toe walking (ITW) is a gait deviation characterized by the persistence of a forefoot strike pattern at initial contact throughout most of the gait cycles beyond the age of three years without an apparent cause[1,2]. The diagnosis is one of exclusion, necessitating the elimination of neurological, neuromuscular, and primary orthopedic abnormalities; therefore, assessing strength, reflexes, and selectivity must be normal[3,4].

Genetic syndromes like McArdle syndrome, muscular dystrophies, autism spectrum disorder (ASD), and peripheral neuropathies-such as Charcot-Marie-Tooth disease and cerebral palsy are highlighted among the differential diagnoses. Children with mild spastic diplegic cerebral palsy have a considerable resemblance to ITW[5]. However, in ITW, there is adequate knee extension at initial contact and the end of the swing in the gait cycle. These characteristics indicate good selective motor control, a primary distinctive factor of cerebral palsy[5,6].

The natural history of ITW remains uncertain, and further studies with higher levels of evidence are required to support decisions on when and how to intervene[7]. Divergence among authors is substantial, with some mentioning spontaneous resolution for most children[8,9]. In contrast, others suggest the persistence of toe walking in approximately 20% to 50% of untreated cases, varying only the severity[10].

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

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The prevalence also lacks consensus, with some citing ITW in approximately 5% of children[8,11], while others point to as much as 24% in the preschool population[5].

The first publication on the subject was made by Hall et al. in 1967[10], describing it as a congenital contracture of the Achilles tendon, commonly referred to as congenital short Achilles tendon, a theory that prevailed until the early 21st century, influencing generations of orthopedic surgeons. However, the subject gained new approaches and nomenclatures over the last two decades, and different classifications were proposed. Currently, the term Idiopathic Toe Walking is the most widely accepted and used.

Several etiological hypotheses have gained visibility, such as the theory of sensory processing dysfunction (SPD), with studies suggesting a possible association with vestibular dysfunctions[12]. Additionally, genetic etiology has been considered, with the potential of an autosomal dominant variable expression characteristic[13]. A positive family history is frequently observed, ranging from 30%[14] to 88%[13].

The main consequences of persistent toe walking include the development of plano-valgus feet, increased external tibial torsion, pain, fatigue, imbalance, and psychological impact[15].

Various severity classification methods have been proposed. In 2007, Alvarez et al. proposed categorizing it into mild, moderate, and severe based on the presence or absence of three primary criteria identified in three-dimensional gait analysis. These criteria include the presence of the first ankle rocker, the presence of an early third rocker, and the predominance of the first wave of ankle plantar flexor moment[16] (Table 1) (Figure 1).

In 2021, Westberry et al. proposed modifying the Alvarez classification, replacing the kinematic assessment of the first ankle rocker with the sagittal ankle kinetics[17]. They introduced a dorsiflexor moment within the initial 10% of the gait cycle as the defining criterion for the first ankle rocker (Figure 2).

Three-dimensional gait analysis adds diagnostic and prognostic value to ITW. Efforts are being made to correlate the most effective treatments for each severity level. However, criticism exists regarding this analysis method, as the environment in which the gait is performed may lead the child to walk differently from their habitual gait. Studies are investigating alternative methods, such as using inertial sensor garments (wearables)[18], though this technique is still under investigation.

The most common treatment methods described in the literature include physical therapy, sensory therapy, serial casting, botulinum toxin A (BoNT-A) injections, orthotic use (2–10 weeks), pyramid insoles, and surgical gastrocsoleus lengthening with or without the use of casting and orthotics.

The objective of this study is to consolidate the current knowledge on ITW, provide a critical overview, and identify areas for potential future research.

Methods

This literature review was conducted following the PICO (Population, Intervention, Comparison, and Outcome) model as the search framework for terms. The following databases were searched from September 2022 to June 2023: MEDLINE, EBSCO, Embase, CINAHL Plus, and PubMed. The keywords were idiopathic toe walking, tiptoe walking, tiptoe gait, gait, and toe walking gait. Inclusion criteria comprised studies involving children diagnosed with ITW discussing diagnosis, risk factors, classifications, treatment, and prognosis. The data analyzed were from published articles in peer-reviewed journals in English. Case reports and studies exclusively focused on patients with cerebral palsy or primary Achilles

Table 1. Criteria for ITW classification. (Adapted from Alvarez et al., 2007)[16]

	Idiopathic Toe Walking: Primary Criteria and Definitions		
	First ankle rocker	Early third rocker	Predominance of the first wave of ankle plantar flexor moment
Type 1	Yes	No	No
Type 2	Yes/No	Yes/No	No
Type 3	No	Yes	Yes

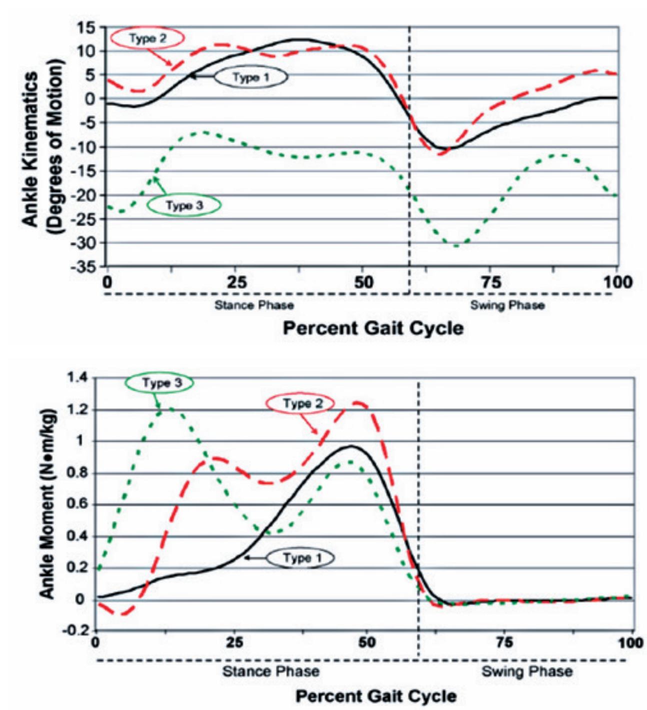
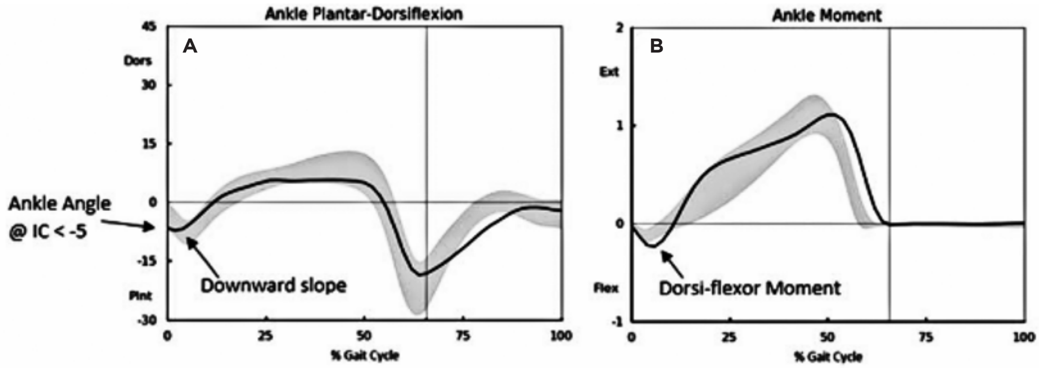


Figure 1. Representation of ankle kinematics and kinetics graphs illustrating the assessed parameters for Alvarez classification. (Reproduced from Alvarez et al., 2007).[16]



	Toe walking severity group	First Rocker Qualifiers			Primary criteria and definitions		
		Ankle Angle at Initial Contact > -5	Down-going ankle excursion	Presence of dorsi-flexor moment	Presence of first ankle rocker	Presence of early third ankle rocker	Predominant first ankle moment
Alvarez	*Type2*	No	Yes		*No*	No	No
Modified Alvarez	*Type1*			Yes	*Yes*	No	No

Figure 2. Representation of the proposed modification by Westberry et al. to the Alvarez first ankle rocker classification, based on the presence of dorsiflexor moment within the initial 10% of the gait cycle in the sagittal plane ankle kinetics. (Replicated from Westberry et al. 2021)[17]

tendon contractures were excluded. The selection process involved reading abstracts, and if they did not meet the exclusion criteria, full articles were assessed.

Results

Age

Kelly et al. (1997)[1] and Sutherland et al. (1980)[2] consider ITW to be the persistence of toe walking beyond the age of three. Sobel et al. (1997)[14], when evaluating children who predominantly walked on their toes since the initiation of walking, observed that 35% of children continued this pattern until age two and 7% between nine and 15 years. Engström and Tedroff (2018)[8] noted that 79% of children with ITW ceased toe walking naturally by the age of ten.

Despite the evident spontaneous improvement in most children, studies by Sobel et al. (1997)[14] and Engelbert et al. (2011)[5] demonstrate that children with persistent toe walking without undergoing treatment have higher rates of shortening and contracture of the calf muscles (Table 2).

Etiology and risk factors

Regarding etiology and potential risk factors, there is ongoing research into family history. In Sobel's et al. study (1997)[14], a positive family history was present in 30% of cases, while Fox et al. (2006)[19] reported 43.3%, Hirsh and Wagner (2007)[20] reported 57%, and Katz and Mubarak (1984)[13] reported 88%. It is important to note that Katz and Mubarak (1984)[13] identified an autosomal dominant condition when investigating Achilles tendon contracture. Although these are different conditions, it is not a factor that can be completely ignored (Table 3).

Pomarino et al. conducted two studies[21,22] on genetic influence on the development of this condition. They observed a higher predominance in male children, raising the question of whether this pathology could have an X-linked recessive autosomal cause associated with 30% to 42% paternal family history presence.

Furthermore, some studies have proposed an association of ITW with SPD[12,23]. It is known that patients diagnosed with ASD might have a higher prevalence of ITW-up to 20.1%- with a high rate of tight heel cords (12%)[24,25]. Since patients with ASD frequently present higher rates of SPD, it may be reasonable to consider this as a possible target in the treatment of ITW.

New studies are also investigating neurological changes between children with and without ITW. Donne et al. (2022)[26] found differences in the neural pathway activation in their study, as the toe walking group showed lower activation in the left frontal lobe region, which indicates a somatosensory difference between groups. However, more studies are needed to determine the true impact of these differences.

Classification of ITW

One of the first reference points to define treatment approaches in different clinical conditions is the severity classification. The most widely used classification for ITW is Alvarez's (2007)[16], based on the presence or absence of the three ankle rocker mechanisms. This classification has been considered highly sensitive according to the Cochrane systematic review by Caserta et al. (2019)[27].

Other aspects have formed the basis for additional classifications. For instance, O'Sullivan et al. proposal (2018)[28] divides children into typical and non-typical-ITW based on differences in gait analysis. Additionally, there are classifications based on anatomical features, as described by Pomarino et al. (2017)[29], highlighting differences in calf shape, forefoot, and Achilles tendon, among others.

Bauer et al. (2022)[30] introduced a descriptive classification for children with toe walking. In a straightforward manner, they divided it into toe walking during developmental stages, ITW with autism, congenital tendon contracture, habitual persistent ITW (without contracture), and finally, persistent ITW with contracture (Figure 3).

Treatment

The literature shows different management options for ITW, including conservative methods such as physiotherapy, orthotics, serial casting, and foot orthoses. Invasive approaches, such as surgical procedures (percutaneous or open), are also considered (Table 4).

Conservative therapies (physiotherapy, serial casting, orthotics, and botulinum toxin injection)

The effectiveness of stretching and physiotherapy sessions as a curative approach to equinus gait was evaluated, and their efficacy was compared to more invasive techniques. When used in isolation, these methods did not show effectiveness[31].

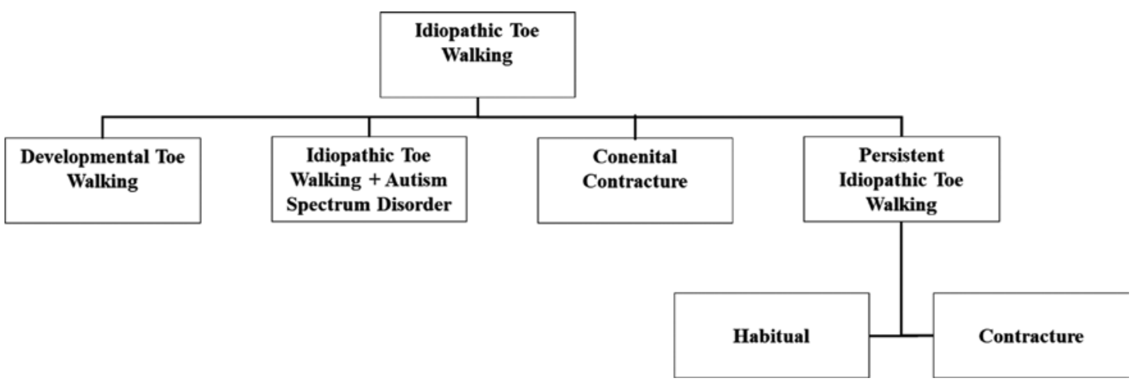


Figure 3. Idiopathic Toe Walking classification, by Bauer et al. (Replicated from Bauer et al., 2022)[20]

Table 2. Studies evaluating spontaneous resolution of ITW

Article	Authors (Publication Year)	Journal, Publication year (impact factor 22/23)	Number of ITW in the sample/ Number of the population in the study	Mean age at the beginning of the study (years)	Conclusions of the study
Idiopathic Toe-Walking: Prevalence and Natural History from Birth to Ten Years of Age	Engström P, Tedroff K (2018)[8]	The Journal of Bone and Joint Surgery (5.3)	63/1401	5.5	- 79% of children with ITW ceased toe walking by age 10. - Among 4 cases of Achilles tendon contractures (defined as <10°of ankle dorsiflexion), two maintained 5°, one worsened from 10° to 5°, and one progressed from 10°/15° to 0° bilaterally.
Effect of Persistent Toe Walking on Ankle Equinus	Sobel E, Caselli M. A, Velez Z (1997)[14]	Journal of the American Podiatric Medical Association (0.7)	60/-	3.5	- There was a male predominance in ITW cases (non-significant p-value). - ITW begins right from the onset of a child's walking, which differs from cerebral palsy cases. - Approximately 30% of cases have a positive family history. - The mean dorsiflexion angle measures 6.2°. - 35% of children exhibited ITW at two years, and 7% between 9 and 15 years. - The presence of ITW decreases with age, accompanied by a decrease in dorsiflexion angle.

Table 3. Studies demonstrating a possible genetic association in children with ITW

Authors (Publication year)	Journal (Impact Factor 22/23)	Percentage of children with positive family history
Katz and Mubarak (1984)[13]	Journal of Pediatric Orthopaedics (1.7)	(88%)
Sobel et al. (1997)[14]	Journal of the American Podiatric Medical Association (0.678)	(30%)
Fox et al. (2006)[19]	Acta Orthopædica Belgica (0.35)	(43.3%)
Hirsh and Wagner (2004)[20]	International Journal of Pediatrics (5)	(57%)
Pomarino et al. (2012)[21]	Foot and Ankle Specialist (0.562)	(30%–42%)

Table 4. Studies that investigated treatment options for ITW

Article (Publication Year)	Authors	Journal (Impact Factor)	Number of ITW sample	Mean age at the beginning of intervention (years)	Mean time of follow-up (years)	Conclusions of the study
Outcomes of Noninvasively Treated Idiopathic Toe Walkers (2017)	Radke K, Karch N, Goede F, Vaske B, Von Lewinsky G, Noll Y, Thren A[11]	Foot & Ankle Specialist (0.562)	101	7.75 (2–17)	1.94	Pyramidal insoles: - 95.5% were used with physiotherapy. - 60% were used in conjunction with orthotics. Resulted in a 95.8% resolution of ITW
Surgical Outcomes for Severe Idiopathic Toe Walkers (2021)	Westberry D. E, Carpenter A. M, Brandt A, Barre A, Hilton S. B, Sarawat P, Davids J. R[17]	Journal of Pediatric Orthopaedics (1.7)	26	9 (6.7–16.8)	3.6	Surgery: - 100% improvement in ITW for those operated on in zone III and 88% for those in zone II.
Serial casting in the treatment of idiopathic toe-walkers and review of the literature (2006)	Fox A, Deakin S, Petigrew G, Paton R[19]	Acta Orthopaedica Belgica (0.35)	44	6.08 (2–14.3)	1.1	Serial casting + stretching: Among 44 cases, 29 (66%) showed a reduction or resolution of ITW and an increase in dorsiflexion
The natural history of idiopathic toe-walking: a long-term follow-up of fourteen conservatively treated children (2004)	Hirsch G, Wagner B[20]	Acta Paediatrica (3.8)	14	6.45 (3–9.9)	14.5	Combination of physiotherapy, stretching, casting, orthotics: - 100% combined with stretching. - 35.7% used with orthotics or casting. Among 14 cases, 8 (57.1%) children ceased ITW.
Idiopathic Toe-Walking: Does Treatment Alter the Natural History? (2000)	Eastwood D. M, Menelaus M.B, Dickens R.V.D, Broughton N. S, Cole W. S, Se M[32]	Journal of Pediatric (2.99)	136	Group: Observational: 4 (1.5–10) Group: Casting: 3.5 (1.5–10.3) Group: Surgical: 6.5 (2.5–14.5)	Group: Observational: 3.2 Group: Casting: 3.7 Group: Surgical: 7.9	Three groups (observational, casting, and surgical): - Observational: Improvement of ITW in 45% and resolution in 12%. - Casting: Improvement of ITW in 41% and resolution in 22%. - Surgical: Reduction of ITW by 50% and resolution by 37%.
Serial ankle casts for patients with idiopathic toewalking: effects on functional gait parameters (2019)	Thielemann F, Rockstroh G, Mehrholz J, Druschel C[33]	Journal of Children Orthopaedics (1.38)	10	(5–15)	< 1	Casting: - Improvement in gait analysis criteria.
Habitual toe-walkers. A clinical and electromyographic gait analysis (1977)	Griffin P. P, Wheelhouse W. W, Shiavi R, Bass W[35]	Journal of Bone and Joint Surgery (5.3)	6	6 (5–9)	<1	Casting: Improvement of ITW in 100%

continue...

...Continuation

Table 4. Studies that investigated treatment options for ITW

Article (Publication Year)	Authors	Journal (Impact Factor)	Number of ITW sample	Mean age at the beginning of intervention (years)	Mean time of follow-up (years)	Conclusions of the study
Long-term gait outcomes following conservative management of idiopathic toe walking (2018) Group: Casting + BoNT-A : 7.2 (4.3-12.2)	Davies K, Black A, Hunt M, Holsti L[36]	Gait & Posture (2.4)	34	Group: Casting + BoNT-A : 7.2 (4.3–12.2) Group: Stretching: 8.7 (4.9–13) Group: Stretching: 8.7 (4.9–13)	13.4	Two groups: Casting + BoNT-A injection; Stretching - Casting + BoNT-A injection: Improvement of ITW in 74%. - Stretching: Improvement of ITW in 35%. - Improvement in gait analysis criteria observed in both groups.
Does botulinum toxin A improve the walking pattern in children with idiopathic toe-walking? (2010)	Engstrom P, Gutierrez-Farewik E. M, Bartonek A, Tedroff K, Orefelt C, Haglund-A˚kerlind Y[37]	Journal of Children's Orthopaedics (1.38)	15	(5-13), Median 9	1	BoNT-A injection + stretching: Improvement in 4 out of 11 cases (36.4%) and resolution in 3 out of 11 cases (27.3%)
IncobotulinumtoxinA Injection for Treating Children with Idiopathic Toe Walking: A Retrospective Efficacy and Safety Study (2022)	Fillipetti M, Picelli A, Di Censo R, Vantim S, Randazzo P. N, Sandrini G, Tassorelli C, De Icco R, Smania N, Tamburin S[38]	Toxins (4.2)	28	8.3 (Standard Deviation 3.1)	<1	Incobotulinumtoxin A: - Improvement in dorsiflexion
Botulinum Toxin A Does Not Improve the Results of Cast Treatment for Idiopathic Toe-Walking (2013)	Engstrom P, Bartonek A, Tedroff K, Orefelt C, Haglund-A˚kerlind Y, Gutierrez-Farewik E. M[39]	Journal of Bone and Joint Surgery-American (5.3)	47	9.4 (5–14.5)	1	Casting with and without BoNT-A injection: No improvement in gait analysis parameters was observed with the addition of BoNT-A injection.
Orthotic treatment of idiopathic toe walking with a lower leg orthosis with circular subtalar blocking (2021)	Berger N, Bauer M, Hapfelmeier A, Salzmann M, Prodinge P. M[42]	BMC Musculoskeletal Disorders (2.3)	22	7 (2.5–13.1)	2	Orthoses: - Improvement of ITW by 73% in 1 year and 64% in 2 years
Effects of wearing a foot orthosis on ankle function in children with idiopathic toe walking during gait (2022)	Brasiliano P, Alvini M, Di Stanislao E, Vannozzi G, Di Rosa G, Camomilla V[43]	Heliyon (3.7)	21	8.3 (5–12)	1.3	Orthosis: - Improvement of ITW by 82% - Enhancement of gait analysis criteria
A comparison of orthoses in the treatment of idiopathic toe walking: A randomized controlled trial (2015)	Herrin K, Geil M[44]	Prosthetics and Orthotics International (1.6)	18	Group: Ankle and Foot Orthosis: 5.4 Group: Foot Orthosis: 4.6	<1	2 groups (ankle-foot and foot orthoses): - Ankle-foot orthosis group: 63% improvement in ITW - Foot orthosis group: 38% improvement in ITW
Outcome after conservative and operative treatment of children with idiopathic toe walking: a systematic review of literature (2014)	Van Bemmel A. F, Van de Graaf, V. A, Van den Bekeom M. P. J, Vergroesen D. A[45]	Musculoskeletal Surgery (0.67)	298	Group: Casting 4.9 (3.3–6.8) Group: Surgical 9 (3.9–12.1)	Group: Casting 3.4 Group: Surgical 4.2	Surgery vs. Serial Casting: - Surgery resulted in higher dorsiflexion values. Gait improvement in 52.5% - Serial casting led to an improvement of 47.9%
Long term gait outcomes of surgically treated idiopathic toe walkers (2016)	McMulking M. L, Gordon A. B, Tompkins B. J, Caskey P. M, Baird G. O[46]	Gait & Posture (2.4)	8	9 (6.4–11.3)	5	Surgery: - 87.5% improvement in ITW (7/8 with first rocker) - Enhancement of gait analysis criteria
Outcome of Patients After Achilles Tendon Lengtheningfor Treatment of Idiopathic Toe Walking (2006)	Hemo Y, Macdessi S. J, Pierce R. A, Aiona M. D, Sussman M. D[47]	Journal of Children's Orthopaedics (1.38)	15	9 (4.2–13.1)	2.9	Surgery: - Enhancement of gait analysis criteria - May lead to knee hyperextension (recurvatum)

Other techniques have also been investigated, including using pyramidal insoles, serial casting, BoNT-A injections, and orthotics. To date, there is only one study published in English evaluating the outcomes of pyramidal insoles[11] and one review[29] where the main author cites four other studies published in German, reporting a success rate between 70%–95.8%[11,29]. Despite these studies demonstrating positive results, they often combined insoles with other therapies involving orthotics, BoNT-A injections, and physiotherapy. Furthermore, they did not have a control group, making it challenging to assess the efficacy of the treatment or whether the good outcomes were not related to the natural history of the disease.

Using serial casting has shown favorable outcomes in some studies[19,20,32,33], including increased ankle dorsiflexion, resolution of ITW, and parental satisfaction with the final results. These positive effects have been observed even in older patients[34,35]. However, some authors still question whether these outcomes could result from the condition's natural progression [32,34,35]. Eastwood et al. (2000) suggest that 50% of children might experience spontaneous improvement[32]. Thielemann et al. (2019) used a functional gait analysis before and after serial casting and at a six-month follow-up visit to compare ten children with ITW submitted to serial casting with a control group. In contrast to the literature, they found complete normalization of the ITW gait compared to the healthy control group, which was observed shortly after treatment[33].

A notable point in serial casting studies is the proposal by Fox et al. (2006)[19] to measure ankle dorsiflexion with the knee flexed, as this seems to be a more accurate indicator of improvement in ITW than measuring with the knee extended. Fox's study showed that while 100% of participants improved ankle dorsiflexion with the knee in extension, only 66% experienced improvement in flexion. Additionally, Davies' study (2018)[36] highlighted compensatory changes observed in older children, such as greater restriction of passive ankle dorsiflexion and compensatory knee hyperextension in both groups. These changes could be due to increased skeletal maturity or longer follow-up periods.

Regarding BoNT-A injections, some studies indicate positive outcomes with improvements in ankle dorsiflexion and other gait parameters[36,37,38], while others do not show significant improvement in ITW[39,40]. Engström et al. conducted two studies[37,39]; the first showed a positive effect on ITW improvement when BoNT-A injection was used combined with isolated physiotherapy[37], but the later study in 2013[39] found no superiority of BoNT-A injection combined with serial casting over serial casting without BoNT-A injection. Caserta et al. (2019)[27], in a Cochrane review, concluded that there are not sufficient studies to confirm that combining BoNT-A injection with serial casting is superior to using serial casting alone. In addition, Sätilä et al. (2019)[41] conducted a randomized controlled trial in 30 children with ITW, dividing them into two groups: (1) a conservative treatment with firm shoes, night splints, a home stretching program, and physical therapy and (2) the same approach with the addition of BoNT-A injections. They reported 38 adverse effects in the BoNT-A group (16 patients treated with 30 injections) and none in the conservative group. No significant differences between the groups in function or ankle range of motion were found in the 24 postoperative months.

Positive results in the short-term follow-up have been reported[42-44] regarding the use of orthotics for ITW. However, ongoing research aims to determine the most effective types of orthotics, suitable age groups, the optimal duration of use, and how long the effects of the intervention last, among other factors. There is no evidence to prove the standalone effectiveness of orthotics as a primary treatment option for ITW.

Invasive therapies: Surgical procedures

There is a consensus that the surgical approach might have better outcomes in treating ITW, as shown in several studies[17,32,45,46]. However, studies still lack addressing the most suitable techniques for different age groups and severity levels. In the study by Westberry et al. (2020)[17], which evaluated 26 patients classified as severe according to Alvarez's classification[16], an 88% improvement was observed with the triceps surae surgical lengthening in zone II, and 100% improvement was seen in those operated in zone III. Among those operated in zone III, none required re-intervention. However, not all children had their symptoms completely resolved; out of the 21 children operated using this technique, 14 were subsequently classified as moderate and seven as mild. Among children undergoing lengthening in zone II, out of the 25 operated extremities, six extremities required revision.

Possible complications after surgery include tendonitis, wound dehiscence, and pain, among others. However, these complications have a low incidence and are usually easily resolved. Compensatory changes such as knee hyperextension (recurvatum) may also occur[29,47], necessitating longer follow-up studies to assess the presence of further abnormalities and the impacts of each of these changes.

Discussion

Despite the heterogeneity in the methodologies of the analyzed studies, certain observations can be noted. The determination of relevant etiological and prognostic factors is still under analysis. A trend towards higher prevalence in boys with a positive family history exists, but the inheritance of the condition remains inconclusive, and higher-level evidence studies are required to confirm these theories. In addition, the association of ITW with SPD and ASD is well established, nonetheless not as a causative factor since many children that present with ITW do not present these conditions.

Regarding the final age of spontaneous resolution, there is variability in the studies regarding the percentage of children exhibiting ITW. The number ranges from 30% to 88%; therefore, it is important to question the reference age used by each author. Engström and Tedroff (2018)[8] use a milestone of 5.5 years, while Kelly et al. (1997)[1] use three years. Thus, some patients showing resolution in Engström's study might not have been considered by Kelly et al., making direct comparison difficult. Furthermore, the follow-up time of studies is questionable. In Engström's study (2018)[8], children with neurodevelopmental disorders-which were not specified-were included in the ITW cohort. Despite this finding, most of the patients ceased toe walking spontaneously, thereby possibly overestimating the value of the ITW in the general population.

Regarding etiology and risk factors, authors such as Fox et al.[19] and Sobel et al.[14] did not find statistically significant evidence for correlations with other demographic data, such as sex, gestational age, and age at diagnosis, among others. However, it is important to consider that the lack of statistical relevance might be due to the small sample size of the cohorts, especially since sex seems to have clinical relevance in discussions from certain studies[14,19,21,22]. As for age, there appears to be a negative correlation between ankle dorsiflexion and age, a hypothesis supported by some studies[36,48], which agrees with the normative data for normal individuals shown in two studies[49,50].

Some authors have raised critical views about established standards of three-dimensional gait analysis, which warrant further investigation and studies to strengthen these opinions. For example, Brasiliano et al. (2023)[51] suggest increased accuracy using multi-segmented three-dimensional gait analysis incorporating foot models. Westberry et al.[17] proposed a modification to Alvarez's classification[16], utilizing the sagittal ankle moment in kinetics to define the first rocker instead of kinematic assessment, as it provides a better representation of the foot's position relative to the tibia, yielding a more precise measure. However, it is important to recognize that three-dimensional gait analysis can only recognize the children's walking pattern in a "snapshot in time," which might not reflect the normal patient's walking pattern since these patients can voluntarily correct their gait at their will[6]. Further studies should compare habitual walking patterns using sensors and three-dimensional gait analysis.

Methods such as stretching, physiotherapy exercises, pyramidal insoles, and BoNT-A injections do not have strong evidence of effectiveness when used in isolation. Many studies have assessed these techniques in combination, making it difficult to distinguish the effect of each one in isolation[11,19,20,37]. It is important to question if the positive effects seen in conservative treatment methods are due to the small sample size, the short follow-up periods that might not account for future presentations, or if they are simply a result of the natural progression of the condition. Weighing the risks and benefits of each therapy may be the best approach for those options.

The most evidence-based conservative measure is serial casting, followed by orthotics. Given the heterogeneity across studies, randomized clinical trials are needed to define optimal casting intervals and orthotic usage. Long-term effects also require investigation. Davies et al. (2018)[36] noted greater knee hyperextension in the stance phase and reduced flexion in the swing phase after serial casting. In contrast, Engström et al. (2013)[39] reported less knee hyperextension in the stance phase and increased knee flexion in the swing phase. Davies et al. attributed these differences to the varying follow-up periods: Davies' study spanned 12 years, while Engström's was only 12 months. The population in the former study also had a higher mean age than in the latter. Further research is necessary in this area, but serial casting seems a good option for gaining ankle dorsiflexion range of motion in mild contractures to improve ankle kinetics and kinematics in the short term.

There is growing evidence of the benefits of surgery in ITW, ranging from symptom reduction to complete resolution in the long term[17,32,45-47]. For severe cases aged near or above ten years, open or percutaneous lengthening in zone III is considered the best choice[17]. However, few robust studies adequately address these questions, demanding randomized clinical trials and better long-term follow-up of proposed interventions.

In our clinical experience, postoperative follow-up often reveals other pre-existing orthopedic conditions, such as increased tibial external rotation and flexible flatfeet. This underscores the importance of conducting a thorough physical exam before treatment and emphasizes the need to educate parents and children about these issues, which might be more evident after treatment. Further research is required to validate these findings, highlighting the significance of early assessment and the value of informing patients and their families about these potential concerns.

Finally, the lack of consensus in results is notable due to the heterogeneity in methodologies, as discussed by Caserta et al. (2019)[40] in their systematic review of outcomes and assessment tools, as well as in Bauer's (2022)[30] and Williams' (2020)[52] findings, which identified a lack of consensus among healthcare professionals regarding evidence-based therapies. Heterogeneity is seen in populations across studies[32,36,45], the type of severity classification used[29,32,42], previous treatments[46,47], and different exclusion criteria[19,42], among other differences, making results comparison unfeasible. For future studies, larger study populations, standardized techniques, follow-up durations, and defined outcome metrics are essential.

This study has some limitations. First, it was restricted to articles in English, excluding some studies in languages like Russian, Italian, Spanish, and others. Second, the methodological heterogeneity of the analyzed articles makes it difficult to explore and compare results. Third, the evaluation included studies other than randomized clinical trials, which decreases the overall evidence levels of the included studies.

Conclusions

Despite the significant heterogeneity in methodologies across studies, it was possible to note a growing trend toward investigating etiological factors, particularly genetic and neurosensory factors, and prognostic factors like age, Achilles tendon contractures, and sex. There appears to be a higher prevalence in boys with a positive family history, yet the genetic inheritance aspect remains inconclusive.

Novel classifications have been proposed based on anatomical features and three-dimensional gait analysis, aiming to differentiate severity, prognosis, and differential diagnoses. Treatment options encompass both conservative and surgical alternatives. Among conservative approaches, there is stronger evidence of gait improvement in equinus gait through serial casting followed by orthotics, while the addition of BoNT-A injections has not shown better results. There is no evidence of sustained improvement with isolated physiotherapy exercises and stretching, but these may be recommended with other therapies. Surgical procedures are reserved for patients with Achilles tendon contractures, with better outcomes observed in severe cases, as per Alvarez's classification, who undergo lengthening in Zone III and are nearly ten years of age or older. However, more robust studies, preferably randomized clinical trials, are needed to establish clearer conclusions about treatment protocols for patients with ITW.

Authors' contributions: All authors read and approved the final manuscript.*ORCID (Open Researcher and Contributor ID) LDLS *(0009-0000-1020-0063), and TOG *(0000-0001-9277-7746) Conceived and planned the activity that led to the study, wrote the article, participated in the review process; LRAA *(0000-0003-3779-6914) Formatting of the article, bibliographic review; FCB *(https://orcid.org/0000-0001-5272-7998), and FMB *(0000-0002-4131-3017) 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

A super-elastic alloy hallux valgus brace – a novel orthotic device

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Abstract

Objective: Evaluate the efficacy of a new orthotic-made super-elastic alloy brace to correct hallux valgus (HV) deformity.

Methods: Five female patients diagnosed with HV deformity wore the newly developed orthotic daily for six weeks. The orthotic was developed using a super-elastic alloy brace to correct great toe lateral deviation, first metatarsal medial deviation, and fixation belts. The correction was evaluated by measuring the load at which the big toe begins to move and the distance moved by 15 gf force when pulled from the side.

Results: The orthotic was worn by all patients without causing any sleep disruptions. In the initial state, a strong force was required to move the big toe, but after two weeks, it was significantly improved to be mobile in all patients. **Conclusion:** The developed HV orthotic has a high wearability without causing pain or discomfort. Long-term use can provide a consistent and continuous correction force to the big toe, resulting in the successful release of the big toe metatarsophalangeal joint contracture within two weeks.

Level of Evidence: Level 4.

Keywords: Hallux valgus; Conservative treatment; Orthotic device; Alloy.

Introduction

Hallux valgus (HV) deformity is a common and potentially debilitating deformity. A variety of orthotics are used to correct HV. To date, effective conservative interventions have been scarce. Conservative treatments commonly used by patients include night splints, foot exercises, and use of orthotics. However, orthotic devices and night splints were no more effective than no treatment for mild-to-moderate patients[(1)]. Furthermore, high-quality evidence for HV conservative treatments is still required[(2)].

When the metals deform beyond the elastic limit of ordinary metals, superelasticity in shape memory alloys exhibits a large recoverable strain and force. In the medical field, super-elastic alloys are now widely used. Ni-Ti (NT) alloys have been used as a painless method for primary orthodontic treatments[(3)] and as a minimally invasive method for lumen stenosis treatment[(4)]. However, the use of NT in orthopedics has not advanced. One obstacle is the form limitation[(4)]. Due to the difficulty of cold working, NT alloys have only been used in simple shapes, such as wires and tubes, in most commercial applications. On the other hand, the Cu–Al–Mn super-elastic alloys discovered by Kainuma et al. in the early 1990s are inexpensive and have excellent workability[(5)], making them easy to process into plates[(6,7)]. A thin Cu–Al–Mn plate has been used to treat ingrowing toenails[(8)].

We present a new nocturnal orthotic-made super-elastic alloy brace to correct hallux valgus (HV) deformity.

Study performed at the Senen Rifu Hospital, Rifu-cho, Miyagi, Japan.

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Methods

Created orthotics

Our objective was to create a supporter-type brace that could be worn stably for long periods without disturbing the patient's sleep. The aim of this brace is to correct great toe lateral deviation and first metatarsal medial deviation.

A super-elastic alloy brace with a hinge joint covered to avoid direct contact with the foot was created. The plate measures 0.4 mm thick, 15 mm wide, 130 mm long (50 mm and 80 mm), and has rounded corners. To allow for toe movement, a hinge joint is attached to the plate (Figure 1).

The belt for the midfoot was made of elastic material and lined with ultrafine nanoparticles. The fibers were made of polyester and hook-and-loop belts to secure the supporter at the midfoot. The belt to secure the big toe was made of the same material as the midfoot. Figure 2 shows the configuration from (1) to (4) of the components of the developed brace.

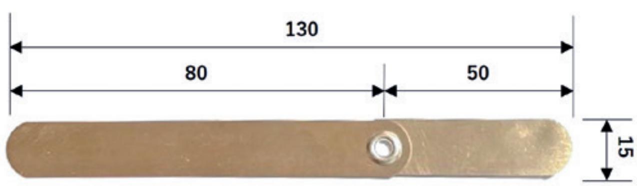

Figure 1. Super-elastic alloy brace with a hinge joint.

Figure 2. Configuration of the components of the developed brace made of ultrafine fiber.

Patients and procedures

Five female patients were diagnosed with HV deformity. The patients' age and initial HV angles are shown in table 1.

The patients were asked to record their daily brace wearing time (Table 1). The correction was evaluated every two weeks after wearing the device in the following manner.

The affected barefoot was placed on a tracing sheet on the measurement table in a sitting position, and the foot shape was traced to evaluate the correction of the big toe metatarsophalangeal (MTP) joint lateral contracture. A loop was attached to the big toe, the big toe was pulled medially, and the force at which the big toe began to move (initial movement value) was measured, as shown in Figure 3.

The same posture was used to pull the big toe until a tensile force of 15 gf was reached, and the distance that the big toe tip moved (traction value) was measured, as shown in Figure 4.

Table 1. Patients and wearing time

Monitor	Age	HV angle (degree)	Daily wearing time (h)
A	50s (F)	34	6.4
B	60s (F)	48	5.5
C	20s (F)	36	13.0
D	60s (F)	29	7.4
E	50s (F)	28	10.2

HV: Hallus valgus; h: hour

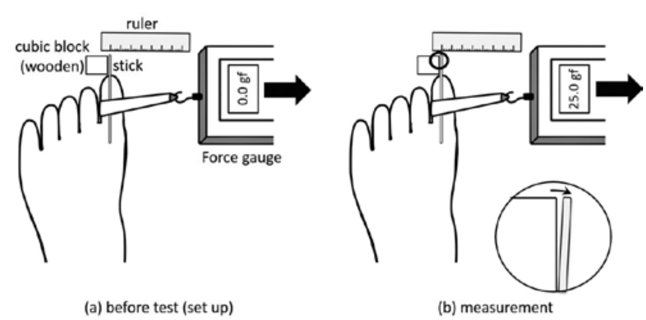

Figure 3. Initial movement value test is shown schematically.

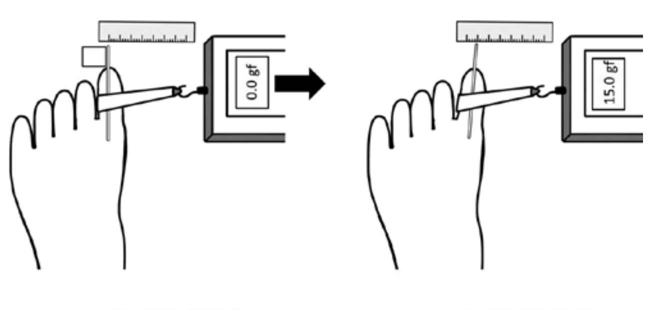

Figure 4. The traction value test is shown schematically.

Results

Wearing period

All patients were able to sleep normally while wearing the brace. The brace received no complaints about steaminess. Although there was some discomfort for about a week after wearing the device, there was no significant discomfort after that, and some patients even forgot they were wearing it.

The force of the initial response

Figure 5 shows the load when the patient's big toe begins to move after two weeks of wearing it. The initial movement values of all patients dropped dramatically two weeks after wearing, and there was no significant change after that. These findings indicate that the brace improves big toe flexibility in the first two weeks.

Toe movement distance when loaded with 15 gf

Figure 6 shows the toe movement distance under 15 gf tensile loading two and six weeks after wearing it. As shown in Figure 6, all patients' big toes did not move under 15 gf tensile loading before brace application, but they did after two weeks. Although there was some variation among patients, in three cases, the greater the movement of the big toe, the longer the patients wore the brace.

Discussion

Hallus valgus can be corrected with a variety of orthotics. Many nocturnal varieties have a rigid inner brace to which the big toe is secured with a belt. Although mechanically effective, they can cause pain when worn by forcibly widening the contracted big toe MTP joint. It is assumed that the greater the HV angle, the greater the pain because the generating force increases linearly due to the linear relationship of the stress-strain response in the normal elastic deformation. Furthermore, most current nocturnal orthotics used for conservative treatment are injection-molded from plastic materials easily formed into three-dimensional shapes. Because of their three-dimensional shape, existing orthotics are rigid and almost nondeforming. As a result, it is easy to imagine they are uncomfortable wearing. Sleep will be disrupted if the material is in direct contact with the skin. The patient experiences patience and stress when wearing these braces at bedtime. Short-time use and/or poor brace fixation appear to be ineffective.

The aim of our orthotic concept is to provide flexible but strong corrective power and comfort for long-term wear. Moreover, unlike traditional nocturnal orthotics, ours can correct the big toe metatarsal varus. We used a super-elastic alloy and ultrafine fiber cloth to develop the brace. Super-elastic alloys are metals with unique properties that allow them to return to their original shape after being subjected to deformation ten times greater than the elastic limit of ordinary metals such as mild steel (see Figure 7). Kainuma et al.[7] developed a copper, aluminum, and manganese alloy with flexible deformation behavior and excellent super-elastic shape recovery.

With an orthotics, the member that imparts corrective force is a Cu–Al–Mn super-elastic alloy. When worn, the super-elastic alloy will deform more by the HV angle due to the flexible nature originating from the stress plateau during deformation, as shown in Figure 8, providing a continuous restoring force. Furthermore, even when the amount of deformation changes, the force applied to the big toe by the super-elastic alloy is nearly constant. It is reasonable to expect that the patient with mild or moderate HV will experience no change in pain. Because nighttime HV orthotics must be worn for extended periods, fit and fixation are critical considerations. All patients in this study could sleep comfortably while wearing the device, with no steaminess or pain. This is due to the ability of the super-elastic alloy to maintain a constant restoring force

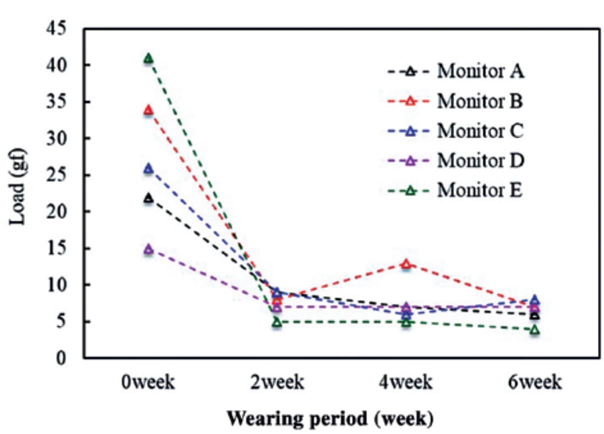

Figure 5. Weight of the moment the big toe begins to move. The traction value test is shown schematically.

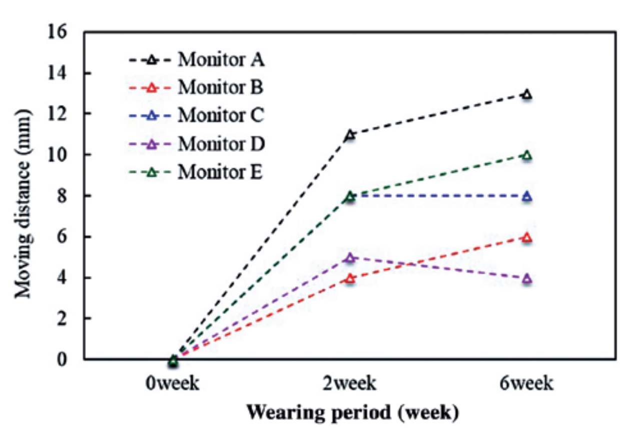

Figure 6. Moving distance of the tip of the big toe when pulled to 15 gf.

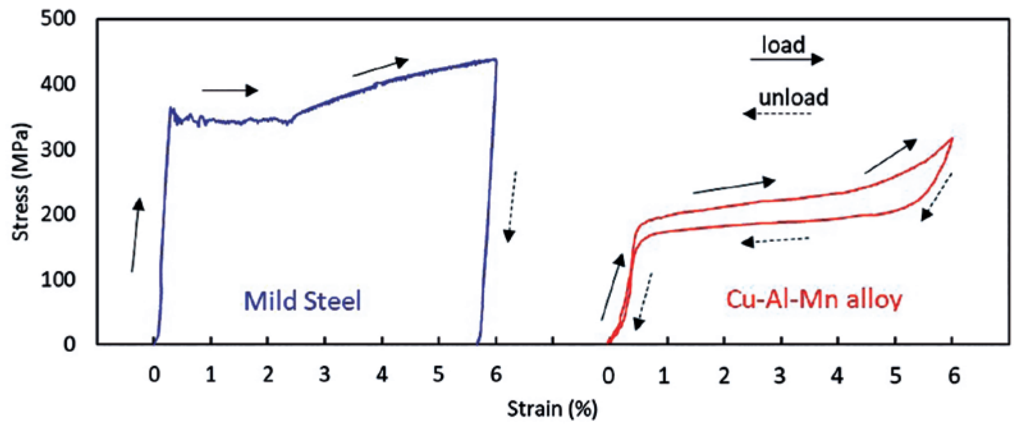

Figure 7. Stress-strain behavior of general mild steel and Cu-Al-Mn super-elastic alloy.

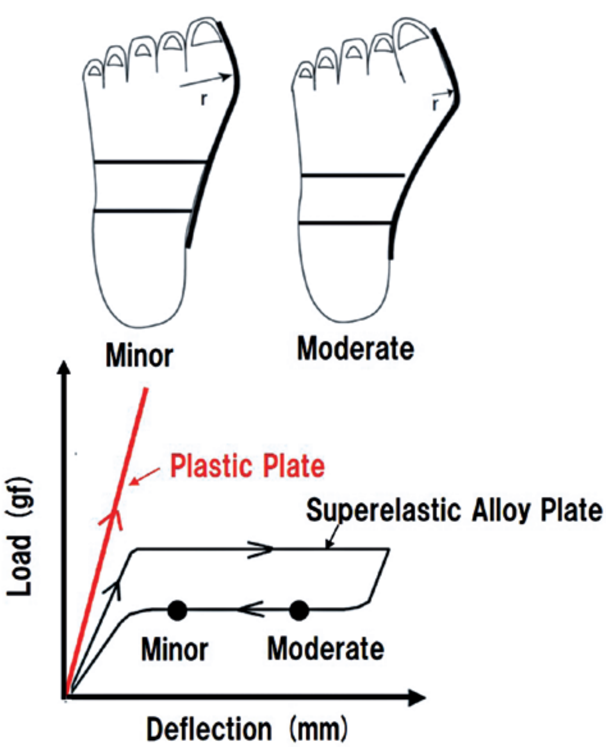

Figure 8. The force applied to each big toe angle by the metatarsal orthotic using super-elastic alloy is shown schematically.

even under large deformations. The high wearability can be attributed to a synergistic effect caused by using microfiber fabrics[9], which allow for comfortable sleeping due to their softness and nonsteaminess[10]. The microfiber fabrics also prevent the brace from slipping off the foot.

The loads for the initial movement and the distance of toe movement at 15 fg load were measured to see if the orthotics could improve the big toe MTP joint lateral contracture. The extensive literature search yielded no such experimental report. Within two weeks of application, the big toe MTP joint lateral contracture had improved. The reason might be that during the long hours of wearing the device at bedtime, a force was constantly applied to the big toe with minimal pain, achieving the same effect as stretching for an extended period. However, there was no discernible improvement in the HV angle during the experimental period. This could be due to the short measurement period and the fact that, even if the contracture improved, it did not sufficiently cause a change in angle. We want to investigate how satisfied patients are with this orthotic and whether there is any improvement in big toe complaints.

Conclusions

We created an orthotic device for HV correction using a Cu–Al–Mn super-elastic alloy brace that can be easily processed into a brace material, which has been difficult with traditional NT alloys. In addition to the super-elastic effect, a hinge mechanism that moves with the big toe and the use of ultrafine polyester fibers to prevent slippage against the skin without causing steam or discomfort to the skin were used to create a brace with both physical and ergonomic functions.

The developed orthotic was monitored by five patients who wore it daily for six weeks, and all patients could sleep comfortably while wearing it.

In the follow-up, all patients experienced relief of the big toe MTP joint lateral contracture within two weeks of wearing the device. This is thought to be due to the effect of long-term stretching while sleeping with a constant force applied to the big toe. We will continue to investigate the possibility of allowing the toes to move more easily, allowing the formation of arches during walking and contributing to reducing calluses, which are common in MTP patients.

Authors' contributions: Each author contributed individually and significantly to the development of this article: MH * (https://orcid.org/0000-0002-8402-5373) Conceived and planned the activity that led to the study, wrote the article, participated in the review process; SK *(https://orcid.org/0000-0002-7455-6349) data collection, bibliographic review; TK *(https://orcid.org/0009-0009-7469-2429) formatting of the article, bibliographic review; TO *(https://orcid.org/0000-0002-9877-5298) Interpreted the results of the study, participated in the review process; RK *(https://orcid.org/0000-0003-0713-6106) Performed the surgeries; data collection, statistical analysis. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Original Article

Non-surgical treatment of ankle sprains: a survey of orthopedic surgeons in Minas Gerais

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Abstract

Objective: Evaluate the diagnostic and therapeutic approach to ankle sprains by orthopedic surgeons in Minas Gerais, Brazil.

Methods: This study was conducted by the Scientific Committee of the Brazilian Society of Orthopedics and Traumatology (SBOT/MG) in 2023. A questionnaire was created on the Google Forms platform with questions regarding the non-surgical approach to ankle sprains. The questionnaire was distributed by email and WhatsApp to SBOT/MG members.

Results: One hundred sixteen orthopedists answered the questionnaire, and 27.6% were foot and ankle specialists. Most of them work in Belo Horizonte city and perform between ten and 30 consultations related to ankle sprains per month. Most professionals request radiographs and prescribe anti-inflammatories. The greatest divergence occurred regarding the use of immobilization. Referral for physiotherapy varied according to the degree of injury.

Conclusion: Strategies for addressing acute ankle sprains are heterogeneous among orthopedists in Minas Gerais, Brazil. The classic treatment protocol is most frequently used in relation to functional treatment.

Level of Evidence IV; Therapeutic Studies; Case Series.

Keywords: Sprains and strains; Ankle injuries; Lateral ligament, ankle.

Introduction

A lateral ankle sprain is the most common acute trauma in sports and accounts for approximately 40% of all sports traumatic ankle injuries[1]. The lateral ligament complex of the ankle is compromised in 80%–85% of these injuries, with the anterior talofibular ligament being the most frequently injured[2,3]. Ankle ligament injuries occur mostly due to inversion trauma and are classified into three degrees, according to their severity[4]. Following the O'Donoghue classification, these injuries occur by stretching (grade I sprain), partial ruptures (grade II sprain), or total rupture (grade III sprain)[5].

The diagnosis can be confirmed by physical examination with specific maneuvers such as the anterior drawer test or with imaging tests. The Ottawa rules were created to guide the request for radiographic examinations in emergency care in case of specific clinical criteria such as referred malleolar pain associated with age > 55 years, inability to bear weight, and bone tenderness in the distal malleolus (6 cm). The initial evaluation is not accurate enough to diagnose the degree of the injury, and the late physical examination, after 4-5 days of trauma, is considered the most reliable for this evaluation[6].

Magnetic resonance imaging (MRI) is widely used to diagnose ligament injuries and provides information on associated injuries, presenting high sensitivity and specificity[7].

Regardless of the injury magnitude, acute ankle sprains are treated non-surgically, using non-steroidal anti-inflammatory drugs (NSAIDs), orthoses, and physical rehabilitation, with

Study performed at the Hospital Felício Rocho, Belo Horizonte, MG, Brazil.

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symptoms improving in around 80% of cases[8]. Despite the increasing number of published studies on the subject[9,10,11], heterogeneity in treatment persists. In the past, conventional treatment delayed the start of weight-bearing, had long immobilization, and started physiotherapy late. Currently, functional rehabilitation recommends early weight-bearing, short immobilization, and early physiotherapy, favoring the maintenance of joint movement with external support for extreme movements, enabling pain improvement and faster return to normal functional activities[9,10,11].

The objective of this study is to evaluate the diagnostic and therapeutic approach to ankle sprains by orthopedic surgeons in Minas Gerais, Brazil.

Methods

This study was conducted by the Scientific Support Committee of the Brazilian Society of Orthopedics and Traumatology in Minas Gerais (SBOT/MG) from June to November 2023. A questionnaire was created on the Google Forms platform with questions regarding the non-surgical approach to ankle sprains. This questionnaire was distributed by email and WhatsApp to the full members of SBOT/MG.

Participants signed the informed consent form (ICF) before answering the questionnaire. The system guaranteed the anonymity of the participants. The response was voluntary and did not benefit or harm the participants. This study was approved by the institutional review board.

The data obtained were analyzed using the Google Forms platform, using frequency and percentage values, and later analyzed in an Excel spreadsheet.

Results

The questionnaire was sent to 1405 physicians of SBOT/MG, and 116 responses were obtained, of which 27.6% were from foot and ankle specialists.

Among the participants, 64.9% work primarily in Belo Horizonte city. Figure 1 shows the number of ankle sprains that participants see monthly, and the majority (58.6%) perform between ten and 30 consultations.

Most orthopedists request ankle radiographs for all patients (68.1%), while 25.9% use the Ottawa criteria. To evaluate grade 3 sprain, MRI was requested at the first visit 56% of the time and in suspected hidden fracture 45.7% of the time. Only 2.6% of participants requested an MRI for all patients. Regarding treatment, 93.1% prescribed NSAIDs, and the majority (67.6%) maintained the use for five days.

In grade 1 sprains, most orthopedists do not perform immobilization (30.2%) or bandage the joint (33.6%), totaling 63.8%. When prescribed, immobilization was maintained for a maximum of two weeks (59.5%). Figure 2 shows the weight-bearing release after the grade 1 sprain. Most authorized full weight-bearing without support (55.2%).

In grade 3 sprains, most orthopedists perform immobilization with orthopedic boots (74.1%). When immobilization was performed, it was maintained for a maximum of four weeks (81.9%). Figure 3 summarizes the weight-bearing release after the grade 3 sprain. Most authorized weight-bearing with support as they tolerate (56.9%).

As for physiotherapy, 31.9% of orthopedists prescribed for grade 1 sprain, while for grade 3 this frequency rises to 88.8%. Figure 4 represents the moment when the patient was referred to physiotherapy. It is observed that this is a heterogeneous conduct. The reasons for not referring some patients to physiotherapy were mainly related to the availability of the service and the lack of experience of the physiotherapist professional in orthopedic cases.

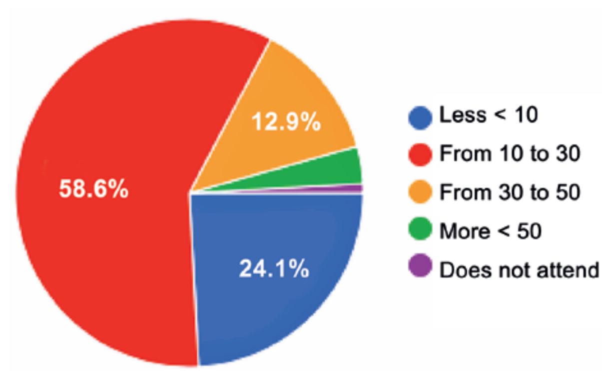

Figure 1. Number of sprains attended monthly.

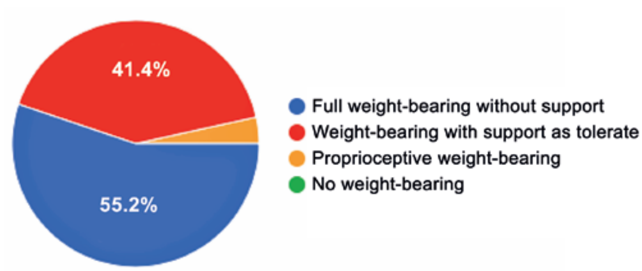

Figure 2. Weight-bearing allowance after grade 1 sprain.

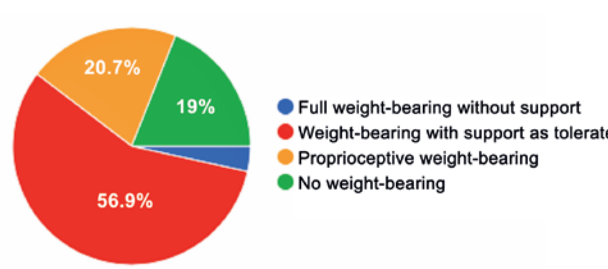

Figure 3. Weight-bearing allowance after grade 3 sprain.

Discussion

The data obtained from this study point to a scenario in which the initial evaluation of this injury by orthopedists from Minas Gerais is uniform for some questions, but there is variation regarding the other items. An important limitation to be considered in the analysis of these data is that less than 10% of the experts who received the questionnaire completed it.

Most participants (68.1%) request radiographs for all patients. Radiographs are used to rule out fractures, although the prevalence is less than 15% in patients who suffer this type of injury[12]. The use of the Ottawa rules is strongly recommended in emergency rooms due to its accurate tool to exclude fractures[12]. Interestingly, only 1/4 of participants use this criterion. The performance of radiographs in selected cases would represent a substantial reduction in costs related to this injury and would reduce the waiting time in emergency services. The challenge is to create legal security for these patients to be discharged without performing radiographs and to create an outpatient clinic for patients to be reassessed in case of the persistence of symptoms.

Regarding the use of medications, most orthopedists (93.1%) prescribe NSAIDs for at least five days. The main objective of these drugs is to reduce pain and local edema, and there is no evidence of the benefit of their use after this period[1].

Regarding immobilization, rigid immobilization is the most current recommendation that does not exceed a period of ten days, and functional treatment should start soon after[9,10]. This study showed variations in the prescription and period of immobilization. Patients with mild sprains are immobilized using bandaging by most orthopedists while patients with severe sprains are immobilized with robofoot-type boots, with wear time ranging from one to four weeks, according to the degree of injury.

Prolonged immobilization has a detrimental effect on muscles, ligaments, and joint surfaces[6]. Several studies have failed to demonstrate a beneficial effect of prolonged immobilization (greater than four weeks). Ideally, immobilization should be restricted to specific conditions (more severe sprains, intolerance to weight-bearing, kinesiophobia) and for short periods[13].

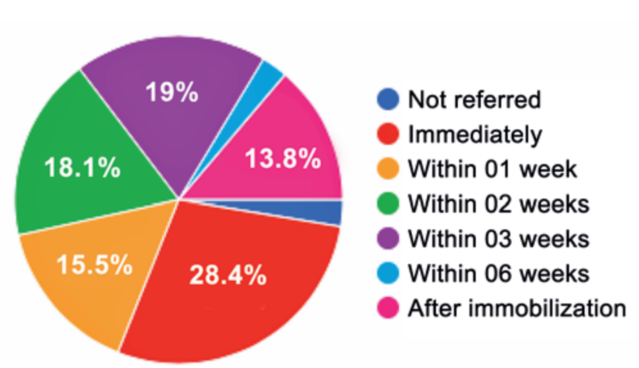

Figure 4. Patient's referral to physiotherapy after ankle sprain.

Functional treatment is most appropriate in cases of ankle sprains as it optimizes the patient's response. It is an early mobilization program associated with flexible external support, such as therapeutic bandages[14]. It is known that flexible functional support, with restriction of extreme movements associated with therapeutic exercises, provides better results compared to rigid immobilization[1]. It is worth remembering that the success of functional treatment depends on the degree of injury [15]. However, what can be observed in the study is that this conduct is very heterogeneous among orthopedists.

The referral for physiotherapy and the moment of onset varied according to the degree of injury. Patients with mild sprain degrees are rarely referred for physiotherapy, while more severe patients are referred to physiotherapy and intervention more frequently. Ideally, early referral to a physiotherapy professional is beneficial to patients, helping to reduce pain, edema, kinesiophobia, and implementing functional treatment[15,16].

For a long time, patients were advised to follow the famous protocol called PRICE, which consists of protection, rest, cryotherapy (ice), compression, and elevation. In view of this change of treatment, the currently recommended protocol is PEACE and LOVE, which is divided into two stages. In the first 72 hours: protection, elevation, avoidance of anti-inflammatories, compression, and education. After 72 hours, the load should progress, be optimistic, accelerate vascularization, and perform exercises[17].

Most orthopedists in Minas Gerais perform conventional approaches to ankle sprains. The patient is immobilized, however the weight-bearing on the lower limb is released. It is noted that joint mobility, related to functional treatment, is often left in the background, despite its proven superiority[14,17]. The variation in the approach to ankle sprain by orthopedists was confirmed by the findings of this study and reinforces the need to offer evidence-based training to update professionals regarding the approach to this injury[14,16].

Conservative treatment performed incorrectly can hinder patient rehabilitation and generate chronic instability, even requiring surgical procedures later. Due to these factors, standardization is necessary, and disseminating it to non-specialists in foot and ankle can facilitate this change to an appropriate functional treatment.

Conclusion

Strategies for addressing acute ankle sprains are heterogeneous among orthopedists in Minas Gerais, Brazil. The classic treatment protocol is most frequently used in relation to functional treatment.

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Original Article

Inter- and intraobserver reliability of the first metatarsal sagittal alignment measurements

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Abstract

Objective: First, analyze the inter- and intraobserver reliability of the angular measurements used to evaluate the first metatarsal sagittal alignment. Second, evaluate whether the anatomical type of foot interferes with the reliability of the measurements.

Methods: The angular measurements used were all those found in the literature, such as first metatarsal declination angle (MDA), first distal metatarsal articular angle (DMAA), first proximal metatarsal articular angle (PMAA), lateral intermetatarsal angle (LIMA), and the angle described by Day. To evaluate interobserver reliability, the Intraclass Correlation Coefficient (ICC) was used; to evaluate intraobserver reliability, the Lin Correlation Coefficient of Agreement (LCCC) was used.

Results: Among all the measurements obtained, the MDA presented the highest ICC and LCCC values in the 40 radiographs evaluated, regardless of the anatomical type of foot.

Conclusion: The first MDA represents an adequate radiographic tool for measuring the first metatarsal sagittal alignment when evaluated by the CCI and LCCC.

Level of Evidence IV; Therapeutic Studies; Case Series.

Keywords: Metatarsal bones; Reliability of results; Radiography.

Introduction

Radiographic measurements are often used to indicate and program orthopedic procedures for forefoot deformities and postoperative follow-up. The first metatarsal is a bone structure with an important function in weight bearing, static, and dynamic. It is commonly related to forefoot deformities such as hallux valgus and hallux rigidus and other complex foot deformities such as progressive collapsing foot deformity[(1)]. Under these conditions, it is often necessary to evaluate whether flexion or extension of the first metatarsal is associated with deformity or after its surgical correction[(2,3)]. However, it is necessary to use measures in which the values are reproducible among surgeons, regardless of the training time[(4-6)].

The objective of this study was first to analyze the inter- and intraobserver reliability of the angular measurements used to evaluate the first metatarsal sagittal alignment. Second, evaluate whether the anatomical type of foot interferes with the reliability of the measurements.

Methods

This is a cross-sectional observational study to evaluate the intra- and interobserver reliability of angular measurements of the first metatarsal sagittal alignment. This study was approved by the Institutional Review Board under the number 64658522.2.0000.0070.

All measurements were performed on a profile view with the foot with a load. The feet radiographs with previous surgeries, equinus deformities, severe cavus feet, and primary or secondary osteoarthritis were excluded from the study. The angular measurements used were all those found

Study performed at the Departamento de Ortopedia e Traumatologia, Hospital Alemão Oswaldo Cruz. São Paulo, SP, Brazil.

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in studies inserted in the main indexed databases (Pubmed, Scielo, Medline, Cochrane, Scopus, and Web of Science), such as (1) first metatarsal declination angle (MDA), (2) first distal metatarsal articular angle (DMAA), (3) first proximal metatarsal articular angle (PMAA), (4) lateral intermetatarsal angle (LIMA), and (5) the angle described by Day.[1,7,8] The references for measuring the first MDA are the angle between one line of the first metatarsal long axis and another line parallel to the ground (Figure 1A). The first DMAA is formed between the anatomical axis of the first metatarsal and a line connecting the dorsal and plantar aspects of the distal joint of the first metatarsal proximal to the sesamoid apparatus (Figure 1B). The first PMAA is formed by the anatomical axis of the first metatarsal and a joint line from the base of the first metatarsal (Figure 1C). The LIMA is obtained between the dorsal cortex of the diaphysis of the first and second metatarsals (Figure 1D). Finally, the angle described by Day is measured by a line drawn from the back to the plantar edge of the first proximal articular surface of the first metatarsal. Another line is drawn parallel to the diaphysis of

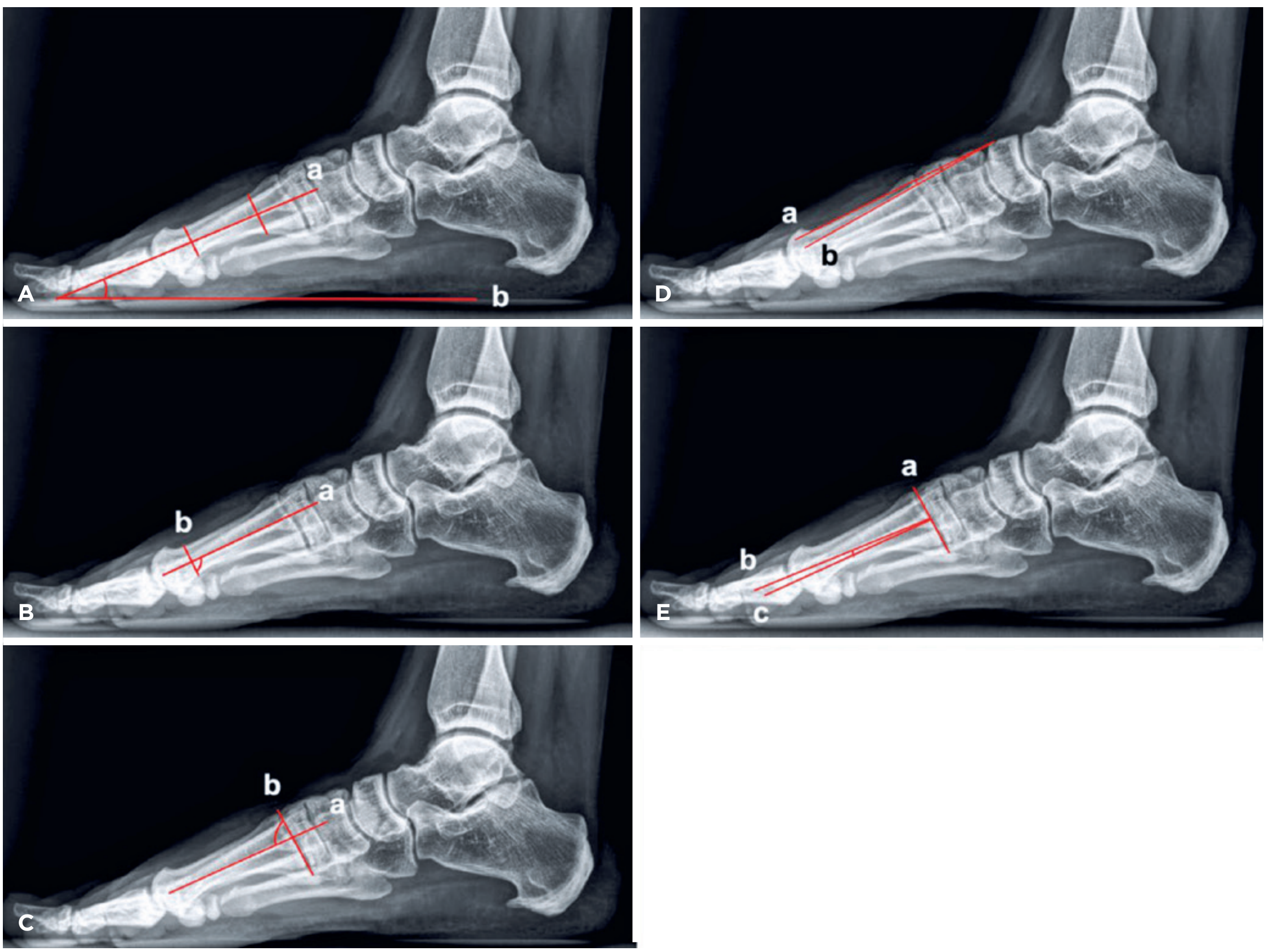

Figure 1. (A) The first MDA is measured from two lines, one the long axis of the first metatarsal (line a) and the other parallel to the ground (line b). **(B)** The first DMAA is obtained by the anatomical axis of the first metatarsal (line a) and the line connecting the dorsal and plantar faces of the distal joint of the first metatarsal proximal to the sesamoid apparatus (line b). **(C)** The first PMAA is formed by the anatomical axis of the first metatarsal (line a) and the articular line of the base (line b). **(D)** The LIMA is obtained between two lines, one along the dorsal cortical of the diaphysis of the first metatarsal (line a) and the other along the dorsal cortical of the second metatarsal (line b). **(E)** The angle described by Day is obtained with three lines. The first is drawn from the dorsal edge to the plantar edge of the proximal articular surface of the first metatarsal (line a). Then, another line is drawn parallel to the diaphysis of the first metatarsal, dividing its head in half (line b). The third is plotted at 90º to the first (line c). The difference between lines b and c form the angle. Abbreviations: First MDA: First metatarsal declination angle; First DMAA: First distal metatarsal articular angle; First PMAA: First proximal metatarsal articular angle; LIMA: Lateral intermetatarsal angle.

the first metatarsal distal to the osteotomy site, bisecting the metatarsal head. The amount that this measurement differs from 90º determines the dorsiflexion angle (Figure 1E). Linear measurements (length) found in the literature were excluded from the study, as their reference points and values can be influenced by the radiographic technique applied in each service.

The measurements were performed by four observers, two newly graduated fellows in foot and ankle surgery (less than one year), and two specialists with more than five years of experience. The sample calculation was previously obtained, which estimated 40 radiographs; therefore, there was significance in the measured values. Inter- and intraobserver reliability assessments were performed on all feet and separately on flatfoot, physiological feet, and cavus feet, according to the Meary angle. When above 10º, the feet were considered cavus, and below -10º, flatfoot.[9] All observers performed the measurements at two different times, with an interval of four weeks. To obtain intraobserver measurements, the most experienced observers were named O1 and O2, and the newly fellows observers were named O3 and O4. The software used to standardize the measurements was the OsiriX software (OsiriX, Switzerland).

Statistical Analysis

To evaluate interobserver reliability, the Intraclass Correlation Coefficient (ICC) was used; to evaluate intraobserver reliability, the Lin Correlation Coefficient of Agreement (LCCC) was used. Both measures determine the degree of correlation among the variables. When the value is < 0.2, the correlation was considered poor; between 0.21-0.4, reasonable; between 0.61-0.80, good and > 0.80, excellent (10.11). Statistical analyses were performed with Jamovi 2.4.8, JASP 0.18, and SAS 9.4 software (SAS Institute Inc, Cary, NC). A p-value of < 0.05 was considered significant.

Results

The first MDA presented the highest ICC values among all the measurements obtained. Considering the 40 feet, the correlation was classified as good, with a value of 0.8 in the first week and 0.78 in the second week (Table 1). When divided into groups according to the anatomical type of feet, the first MDA also showed better ICC values in the first- and second-week. The physiological feet presented the first MDA values of 0.66 in the first week and 0.71 in the second week, which was considered good. For cavus feet, the measurement of the first week was considered good (0.64), and in the second week it was considered moderate (0.56). Both measurements were considered moderate in the flatfoot, with 0.58 in the first week and 0.60 in the second week. As for the other measures, all values were below 0.29 (Table 2).

The first MDA also presented the highest values in intraobserver reliability. Considering the 40 feet, the LCCC presented a good correlation, with values above 0.74 for all members in the first- and second-week. The other measures showed a poor to moderate correlation, with values below 0.48 (Table 3). The values obtained in the evaluation of O1 and O2 were higher, but those obtained by O3 and O4 were close. In the LCCC evaluation, according to the anatomical type of foot, the values of all measurements were variable between observers. The first MDA generally presented higher and closer values (Table 4). The first MDA correlation of O1 and O2 for the physiological feet was considered good, with

Table 1. Intraclass Correlation Coefficient results of all feet after first- and second-week measurements

Measures	N	ICC Week 1	95% CI	ICC Week 2	95% CI
First MDA	40	0.81	0.71–0.88	0.78	0.67–0.86
DA	40	0	-0.11–0.16	0.11	-0.03–0.28
First DMAA	40	0	-0.11–0.16	0.17	0.03–0.35
First PMAA	40	0.17	0.03–0.35	0.11	0.11–0.45
LIMA	40	0.16	0.02–0.34	0	0–0.31

ICC: Intraclass Correlation Coefficient; CI: Confidence Interval; First MDA: First metatarsal declination angle; DA: Angle described by Day; First DMAA: First distal metatarsal articular angle; First PMAA: First proximal metatarsal articular angle; LIMA: Lateral intermetatarsal angle.

Table 2. Intraclass Correlation Coefficient results after first and second-week measurements, according to the type of foot

	N	ICC Week 1	95% CI	ICC Week 2	95% CI
Physiological feet - First MDA	14	0.66	0.42–0.85	0.71	0.48–0.88
Physiological feet - DA	14	0	-0.16–0.31	0.07	-0.12–0.40
Physiological feet - First DMAA	14	0.07	-0.12–0.39	0.12	-0.09–0.45
Physiological feet - PMAA	14	0.27	0.03–0.60	0.29	0.04–0.61
Physiological feet - LIMA	14	0.27	0.02–0.59	0.19	-0.04–0.52
Cavus feet - First MDA	13	0.64	0.38–0.85	0.56	0.29–0.80
Cavus feet - DA	13	0	-0.17–0.32	0.19	-0.04–0.54
Cavus feet - First DMAA	13	0.03	-0.15–0.36	0.01	-0.16–0.34
Cavus feet - First - PMAA	13	0.21	0.03–0.55	0.26	0.01–0.60
Cavus feet - LIMA	13	0.09	-0.11–0.44	0.22	-0.02–0.57
Flatfoot - First MDA	13	0.58	0.31–0.82	0.60	0.33–0.83
Flatfoot - DA	13	0.07	-0.12–0.42	0	-0.17–0.32
Flatfoot - First DMAA	13	0	-0.17–0.32	0.19	-0.04–0.54
Flatfoot - First PMAA	13	0.02	-0.15–0.35	0.10	-0.10–0.45
Flatfoot - LIMA	13	0.07	-0.13–0.41	0	-0.17–0.32

ICC: Intraclass Correlation Coefficient; CI: Confidence Interval; First MDA: First metatarsal declination angle; DA: Angle described by Day; First DMAA: First distal metatarsal articular angle; First PMAA: First proximal metatarsal articular angle; LIMA: Lateral intermetatarsal angle.

Table 3. Lin Correlation Coefficient of Agreement results after measurements of the four observers, considering all feet

Measures	N	LCCC O1	95% CI	LCCC O2	95% CI	LCCC O3	95% CI	LCCC O4	95% CI
First MDA	40	0.90	0.83–0.95	0.80	0.66–0.89	0.74	0.56–0.85	0.76	0.59–0.86
DA	40	-0.06	-0.36–0.25	-0.14	-0.43–0.16	0.03	-0.16–0.22	0.03	-0.16–0.22
First DMAA	40	0.43	0.20–0.62	0.19	-0.11–0.46	-0.14	-0.34–0.08	-0.02	-0.27–0.23
First PMAA	40	0.46	0.19–0.67	0.37	0.08–0.61	0.47	0.19–0.67	0.03	-0.28–0.33
LIMA	40	0.26	-0.05–0.52	0.32	0.06–0.55	0.48	0.21– 0.68	0.10	-0.14–0.32

N: Number of radiographs; LCCC: Lin Correlation Coefficient of Agreement; ICC: Intraclass Correlation Coefficient; CI: Confidence Interval; O: observer; First MDA: First metatarsal declination angle; DA: Angle described by Day; First DMAA: First distal metatarsal articular angle; First PMAA: First proximal metatarsal articular angle; LIMA: Lateral intermetatarsal angle.

Table 4. Lin Correlation Coefficient of Agreement results after first-week measurements of four observers, according to the type of foot

Measures	N	LCCC O1	95% CI	LCCC O2	95% CI	LCCC O3	95% CI	LCCC O4	95% CI
Physiological feet - First MDA	14	0.79	0.55–0.91	0.90	0.74–0.96	0.55	0.20–0.78	0.44	-0.07–0.77
Physiological feet - DA	14	0.04	-0.45–0.52	-0.06	-0.54–0.45	0.10	-0.20–0.40	-0.17	-0.43–0.11
Physiological feet - First DMAA	14	0.31	-0.08–0.62	0.29	-0.25–0.70	0.03	-0.09–0.15	-0.20	-0.59–0.26
Physiological feet - PMAA	14	-0.03	-0.33–0.27	0.69	0.27–0.89	0.64	0.27–0.84	-0.24	-0.66–0.30
Physiological feet - LIMA	14	0.43	-0.06–0.76	0.42	-0.09–0.75	0.64	0.27–0.84	0.04	-0.28–0.35
Cavus feet - First MDA	13	0.88	0.67–0.96	0.55	0.18–0.78	0.68	0.23–0.89	0.53	0.02–0.82
Cavus feet - DA	13	-0.33	-0.71–0.21	0.15	-0.23–0.49	-0.17	-0.60–0.33	0.10	-0.22–0.40
Cavus feet - First DMAA	13	0.75	0.41–0.91	0.28	-0.21–0.66	0.17	-0.29–0.57	0.22	-0.32–0.65
Cavus feet - First - PMAA	13	0.38	-0.16–0.75	0.43	-0.11–0.77	0.50	-0.03–0.81	0.13	-0.41–0.60
Cavus feet - LIMA	13	0.29	-0.27–0.70	0.45	0.05–0.73	0.34	-0.13–0.69	-0.19	-0.55–0.23
Flatfoot - First MDA	13	0.76	0.41–0.91	0.52	0.04–0.80	0.41	-0.15–0.77	0.56	0.10–0.82
Flatfoot - DA	13	-0.10	-0.58–0.43	-0.24	-0.53–0.09	0.05	-0.08–0.18	0.17	-0.25–0.54
Flatfoot - First DMAA	13	0.24	-0.09–0.52	0.21	-0.04–0.43	-0.45	-0.78–0.06	-0.08	-0.40–0.25
Flatfoot - First PMAA	13	0.39	-0.16–0.75	-0.46	-0.80–0.09	0.13	-0.36–0.56	0.38	-0.17–0.75
Flatfoot - LIMA	13	0.07	-0.45–0.56	-0.14	-0.51 – 0.28	0.44	-0.06–0.76	0.35	-0.17–0.71

N: Number of radiographs; LCCC: Lin Correlation Coefficient of Agreement; ICC: Intraclass Correlation Coefficient; CI: Confidence Interval; O: observer; First MDA: First metatarsal declination angle; DA: Angle described by Day; First DMAA: First distal metatarsal articular angle; First PMAA: First proximal metatarsal articular angle; LIMA: Lateral intermetatarsal angle.

values above 0.70. The values of O3 and O4 were below 0.60. For cavus feet, the values of O1 and O3 were classified as good, with values above 0.60. The LCCC measurements obtained by O2 and O4 were below 0.60. For flatfoot, only O1 obtained values considered good, above 0.70. The remainder presented values below 0.60.

Discussion

Any measure used to classify deformities and schedule the surgical procedure must present reproducible values. Our study showed that of all the angles previously described to evaluate the first metatarsal sagittal alignment, the first MDA had the highest inter- and intraobserver correlation values.

In the literature, few studies address the angular measurements used in the forefoot in profile view. Many evaluated only the inter- and intraobserver reliability of radiographic measurements in anteroposterior (AP) view in pathologies such as hallux valgus and metatarsal adduction. Chi et al. demonstrated in a 32-foot study that the distal metaphyseal joint angle presented low interobserver reliability, measured by Scheffe's F test. The images were evaluated by three residents in training and foot and ankle surgery [(12)]. Dawoodi and Perera evaluated three measurements' inter- and intraobserver reliability to calculate forefoot adduction at AP view in 50 radiographs. Only one observer obtained measurements with an interval of three weeks. The ICC values obtained were from 0.85 to 0.92 [(13)]. A new measure to evaluate the extent of the first metatarsal in profile view in patients with hallux valgus and hallux rigidus was described by Bouaicha et al. To obtain the measurement, the authors used a circumference centered on the head of the first metatarsal and a line on its dorsal cortical as references. Despite presenting excellent interobserver correction (ICC = 0.90), the measurement was linear and not angular [(1)]. In contrast, we did not conduct a study to evaluate a new measure but to investigate whether those already described are reliable enough to be used in clinical practice. In addition, only the angular measurements were included to avoid possible technical interference in the radiographs. Gibboney et al. performed a study with radiographic measurements of the foot and ankle in profile view, in which specialist, resident, and academic physicians calculated the values. They demonstrated that the highest values of interobserver reproducibility were found in the group of residents, followed by specialists and academics[6].

The higher ICC and LCCC values observed in the first MDA measurements can be justified by their more evident reference points, based on the first metatarsal and the ground line, with less interference caused by the cuneiforms overlap, metatarsals, and smaller toes. Thomas et al. evaluated measurements of the forefoot in the AP and profile views and demonstrated that the boundary of reference points is usually inconsistent [14]. The low values observed in the other measurements possibly reflect the difficulty that observers had in accurately identifying the proximal joint surfaces and dorsum of the second metatarsal. In a study that evaluated the first metatarsal sagittal alignment after correction of hallux valgus with the Lapidus technique, Nishikawa et al. [2] demonstrate that the first MDA is reproducible with excellent ICC, with mean values of 0.90. Unlike what was observed in our study, Lamm et al. [3] obtained high ICC values in the first PMAA (0.739) and the first DMAA (0.814) measurements in the 24-foot analysis. However, all evaluations were performed by senior surgeons, and there was no division of radiographs into anatomical types of foot.

Our study is the first to include the most used measures to estimate the first metatarsal sagittal alignment and evaluate its inter- and intraobserver reliability. The importance of its results is to assist in the choice of angular measurement with more evident reference points and more reproducible results, thus facilitating the programming of procedures and postoperative follow-up.

The study has limitations regarding the number of radiographs and technical limitations. However, the sample calculation was previously obtained, so the result was relevant. Although we exclude conditions that could technically interfere with obtaining an adequate radiograph, the radiographic analysis is two-dimensional, which can influence the foot position[15,16].

Conclusion

The first MDA represents an adequate radiographic tool for measuring the first metatarsal sagittal alignment when evaluated by the CCI and LCCC.

In addition, among all the angles evaluated, the first MDA presented higher values in intra- and interobserver correlation, regardless of the anatomical type of foot. However, more studies are needed to corroborate our results and define the best measures.

Authors' contributions: Each author contributed individually and significantly to the development of this article: DRCN *(https://orcid.org/0000-0003-0227-2440), and DLR *(https://orcid.org/0000-0003-0183-8641), and PBR *(https://orcid.org/0000-0002-7215-8187) Conceived and planned the activities that led to the study, wrote the article, participated in the revision process and approved the final version; PBR *(https://orcid.org/0000-0002-7215-8187), and DKPG *(https://orcid.org/0000-0001-7552-6590), and TBS *(https://orcid.org/0009-0002-9385-2044), and DAS *(https://orcid.org/0009-0008-8395-8797) Performed all radiographic measurements that were the subject of evaluation in the study; PBR *(https://orcid.org/0000-0002-7215-8187),and DRCN *(https://orcid.org/0000-0003-0227-2440), and DLR *(https://orcid.org/0000-0003-0183-8641), and TSM *(https://orcid.org/0000-0003-4168-0981), and CDF *(https://orcid.org/0000-0002-6649-2066), and FDPR *(https://orcid.org/0009-0007-9143-1162). Interpreted the results and participated in the review process and 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

Correlation between the region of interest in digital radiography, Hounsfield units, and histological maturation on Wistar rats submitted to tibial fracture

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Abstract

Objective: Study the relationship between the region of interest (ROI) and Hounsfield units (HU) in the tibial bone callus.

Methods: Twenty-one adult Wistar rats were submitted to tibial fracture. The fracture was radiographed after their euthanasia, and the bone calluses were analyzed histologically after being stained with hematoxylin and eosin. Euthanasia occurred between the 2nd and 6th weeks after fracture and fixation, thus obtaining various consolidation stages. Histologically, vessels, chondroblasts, connective tissue (collagen), maximum size of the chondrocyte, and the concentration of chondrocytes were quantified.

Results: It was observed that the higher the HU, the more mature and closer to bone consolidation it is, proving that the use of ROI and bone callus measurement with HU is reliable for the histological process of maturation of the bone callus and can be safely used as proof of evolution of the bone healing process.

Conclusion: The ROI was successfully used in digital radiography to observe HU in fractured bones.

Level of Evidence IV; Therapeutic Studies; Case Series.

Keywords: Fracture healing; Digital radiography; Hounsfield units; Histomorphometry.

Introduction

The fracture healing process is complex and carefully coordinated, having evolved over eons as an essential adaptation for the survival of healthy individuals[1].

The bone consolidation process and its stages have been studied over the years. These studies are evaluated using invasive and traumatic techniques, often requiring the death of the individual being evaluated. The use of radiographs and computed tomography (CT) scans to assess the evolution of the bone callus until final healing (complete consolidation) has been used thanks to the Hounsfield units (HU)[2,3].

These units are a relative quantitative measure of radiodensity used by radiologists in interpreting images. The absorption/attenuation coefficient of radiation within a tissue produces a grayscale image. The physical density of the tissue is proportional to the absorption/attenuation of the radiograph beam; that is, the denser it is, the more HU a tissue has. The HU analysis is used to identify pathologies in the most diverse types of tissues, such as liver[4], bone[5], vascular[6], and renal[7], among others, due to its objective method rather than a subjective one.

Interest in studying the bone healing process has increased over time due to several factors, particularly the significant increase in metabolic bone diseases and a concomitant increase in fragility fractures, both because of these diseases and the longer life expectancy[8].

Study performed at the Serviço de Cirurgia do Pé e Tornozelo, Hospital Municipal Lourenço Jorge, Rio de Janeiro, RJ, Brazil.

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The region of interest (ROI) means a specific area of interest of the radiograph that will be submitted to analysis without interference from the rest; that is, it will be processed separately in the computer[9,10]. As the search for new parameters to evaluate bone consolidation is essential to avoid costly and unnecessary methods, the objective of the study is to verify a possible relationship between HU and bone callus maturity through an ROI analysis of the fractured tibia of Wistar rats.

Methods

Ethical aspects

The study was performed at the Laboratory of the Urogenital Research Unit of the Universidade Estadual do Rio de Janeiro (UERJ).

The handling of the animals followed the principles described in The Guide for the Care and Use of Laboratory Animals[11], CIOMS ethical code for animal experimentation[12], and Use of animals in experimental surgery[13]. This study was approved by the Ethics Committee for the care and use of experimental animals of the Instituto de Biologia Roberto Alcântara Gomes of the Universidade Estadual do Rio de Janeiro (CEUA/020/2021). This study was conducted in accordance with the ARRIVE 2.0 guidelines[14].

Animal model and sampling

Adult 90-day-old Wistar rats (Rattus norvergicus albinus) were used. The sample size was chosen as five animals per minimum in accordance with other experimental studies in rats with this timeframe (4 weeks); thus, the chosen sample was by convenience. In total, 25 animals were included; however, only 21 animals were analyzed, as four died due to complications during anesthesia.

Determining the time of analysis

To evaluate the healing process of fractures in their different evolutionary stages, 21 animals were used. The distribution and selection of the animals was performed by probabilistic allocation using a simple draw without replacement and they were sacrificed between two and six weeks after the fracture.

Production of fractures

The animals were anesthetized using ketamine hydrochloride (Laboratório Pfizer Ltda., São Paulo, SP, Brazil) at a dose of 40 mg/kg/weight associated with xylazine (Virbax® 2%, Virbac do Brasil, Jurubatuba, SP, Brazil) at a dose of 5 mg/kg/weight, intramuscular injection in the medial surface of the animal's right thigh. Animals that presented regular breathing, flaccid skeletal muscles and absence of reflexes were considered anesthetized.

A metallic wire of 1 mm in diameter was introduced into the medullary canal of the tibias[15], and subsequent production of the fracture in the middle third of the two tibias of the rats mechanically (7.5 joules per cm^2) with a guillotine (Figure 1), with three support points on the diaphysis described by An et al. (1994)[16], similar in terms of trait and without exposure to the external environment, after realigning the fragments, thus facilitating the histological cuts. With clinical evidence of the fracture, that is, mobility in the focus, and radiological control (Figure 2); after recovery from anesthesia, the animals were placed back in the previously identified boxes, with water and food ad libitum.

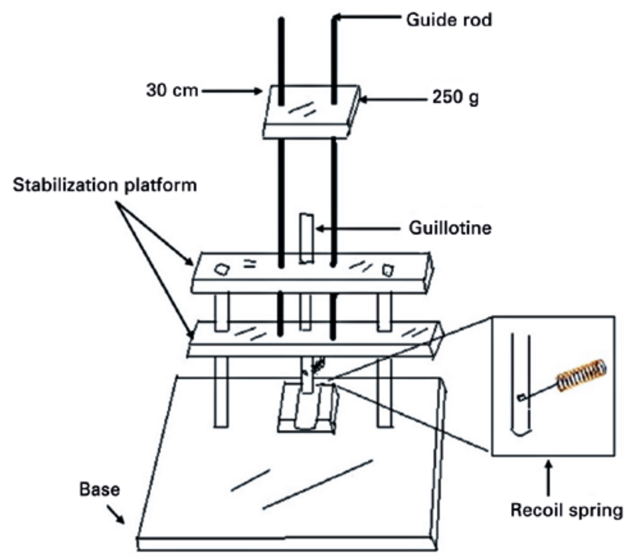

Figure 1. Schematic model of the guillotine.

Figure 2. Radiological control after fracture.

Between two and six weeks, the animals were sacrificed using ketamine at a dose of 50 mg/kg/weight associated with xylazine at a dose of 10 mg/weight. kg/weight, intraperitoneally.

Histopathological analysis

After euthanasia (inhalation of isoflurane followed by exsanguination), the tibias were removed by means of disarticulation at the ankles and knees. The tibias were dissected, maintaining the periostium envelope around the fracture focus. The surgical instruments used during this procedure were disinfected using a 2% glutaraldehyde solution for 30 minutes. All organs were harvested for other studies regarding stress fractures and the animals remains were incinerated.

The pieces obtained were fixed for 48 hours in a formalin solution (10% formaldehyde, 37%, 0.65% Na_2HPO_4, pH7.2). Initially, the pieces were washed in running water and demineralized in ETDA for 48 hours, after these 48 hours the tibias were longitudinally sectioned and returned to the ETDA for another 24 hours to complete the demineralization. Then, the pieces were washed again in running water, the bone ends without bone callus were removed, the bone callus region was then dehydrated in 70%, 80%, 90% and 100% alcohol baths, cleared in xylol and included in paraffin. The material was sectioned on an RM2125RT microtome (Leica, Heerbrugg, St.Gallen, Switzerland) obtaining consecutive 5μ sections, which were stained with Hematoxylin & Eosin (HE).

Vertical sections of the fracture site were analyzed using an optical microscope at 200X magnification and adapted to a digital camera. Histomorphometric analysis was performed, evaluating the area of the bone callus, quantifying vessels, chondrocytes, connective tissue (collagen) and the maximum size of the chondrocyte, as well as the concentration of chondrocytes in each animal. For this analysis, the Image J software (®National Institutes of Health, USA) was used.

Digital radiographic analysis

The radiographic examinations were performed in the same day of the euthanasia and processed in the radiology sector of the Hospital Universitário Pedro Ernesto (HUPE) with all radiological safety standards respected. All paws were identified with animal number and laterality (Figure 3).

The images were analyzed using the RadiAnt viewer (with Anvisa approval) applying a ROI, a surrounding ellipse capable of reading and measuring the HU, in the tibial fracture zone. To normalize the measurement, the HU value was reduced from the most hypodense point on the screen, thus analyzing the anterior region of the callus (area of mechanical tension) and the posterior part of the callus (area of compression), thus allowing a analysis whether the changes were proportional in the two regions that are mechanically distinct (Figure 4).

Statistical analysis

Descriptive statistical analysis (mean and standard deviation) was performed. Spearman's correlation test was performed to verify correlations between the HU value and the mean percentage of collagen, vessels, intermediate connective tissue, calcium, and chondrocytes.

For all analyses, a p value < 0.05 was considered significant and the SPSS 23 software was used to perform the statistical analysis.

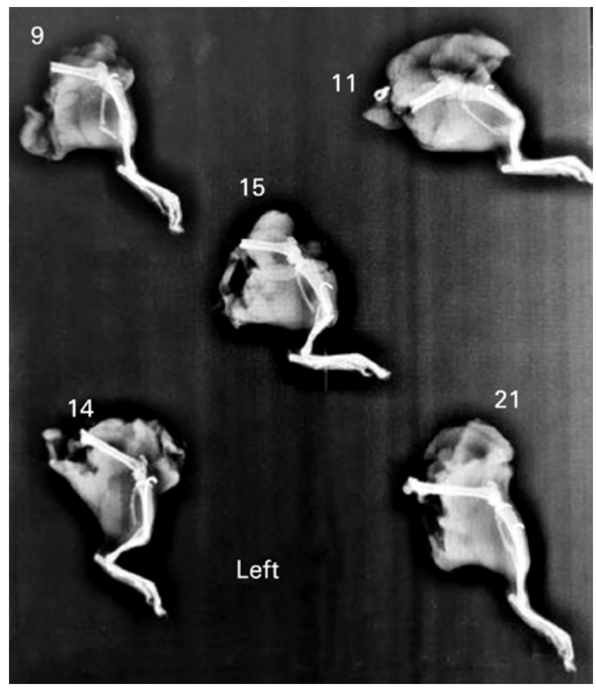

Figure 3. Radiological image of the animals and the side of their fracture.

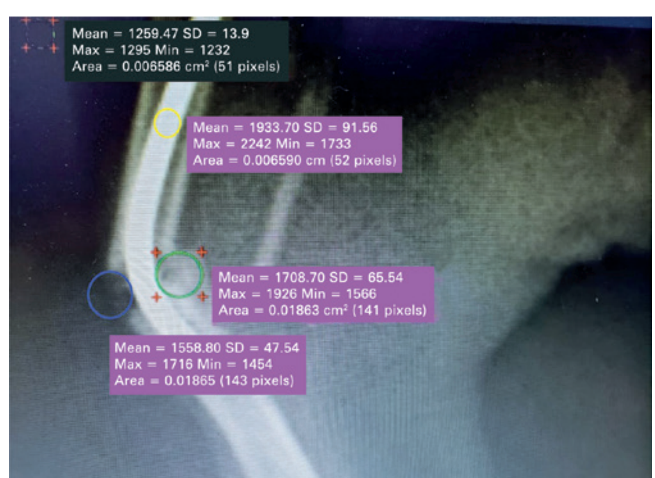

Figure 4. Region of interest.

Results

No rats died of complications during surgery, fracture procedure or implant. There were no adverse events throughout the study.

It was observed that the higher the HU, the lower the concentration of connective tissue with collagen (Figure 5) albeit without statistical significance ($p = 0.13$), the greater the intermediate connective tissue, the greater the HU, without statistical significance ($p = 0.10$) (Figure 6). The HU levels were significantly proportionate with calcium levels ($p = 0.01$) (Figure 7). When evaluating the concentration of chondrocytes, the same pattern found in collagen was identified, the lower the concentration of chondrocytes, the greater the HU with statistical significance ($p = 0.003$) (Figure 8) and when quantifying the blood vessels, it was verified that the HU is not significantly ($p = 0.29$) altered proportionally with its concentration, presenting only a tendency for the HU to increase as the concentration of vessels decreases (Figure 9).

The histological findings showed osteoblasts, connective tissue, and vessels compatible with the bone healing process (Figure 10).

Discussion

Fractures are one of the most common medical events in the general population. Failure in the healing process leads to nonunion, and account to 5% to 10% of long bones fractures. It leads to financial impact due to longer hospital stay, more complex surgeries, increased prescriptions, and overall healthcare resources utilization[17].

Bone healing is a well-known and described process which is affected by several factors: nutrition, age, comorbidities. Histological analysis of a bone healing slide typically reveals different stages of the healing process, depending on the time

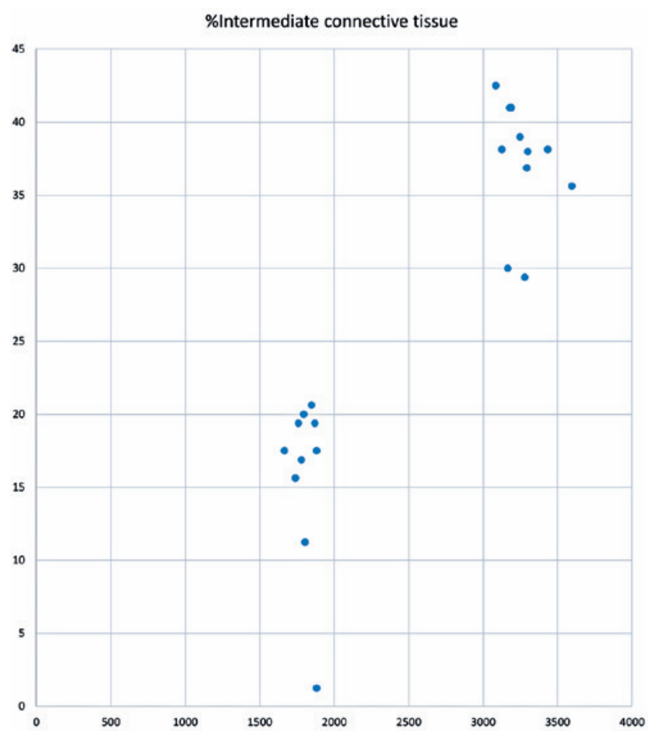

Figure 6. Mean percentage of intermediate connective tissue and its relation to Hounsfield units.

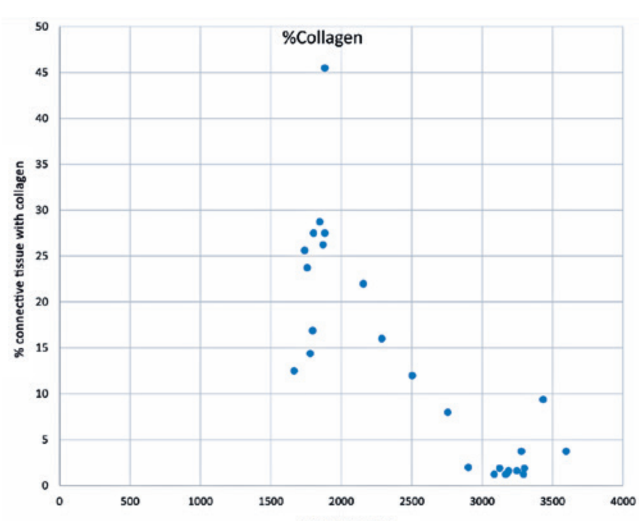

Figure 5. Mean percentage of collagen and its relation to Hounsfield units.

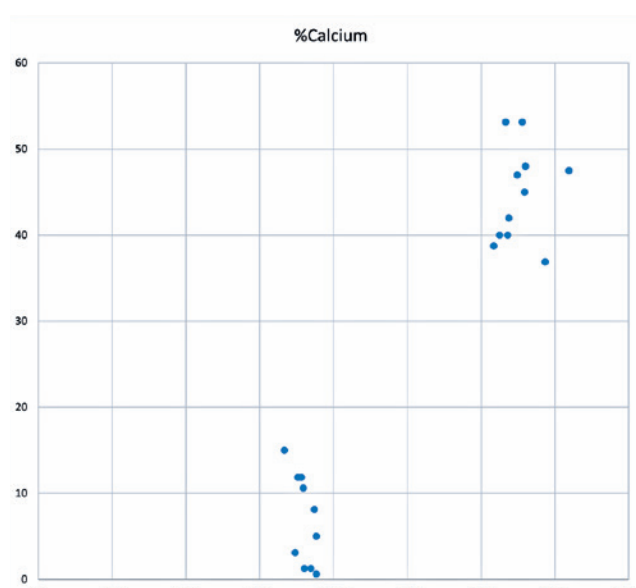

Figure 7. Mean percentage of calcium and its relation to Hounsfield units.

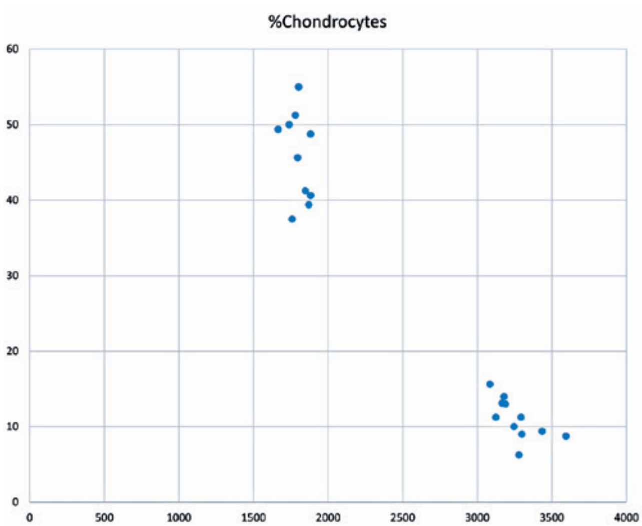

Figure 8. Mean percentage of chondrocytes and its relation to Hounsfield units.

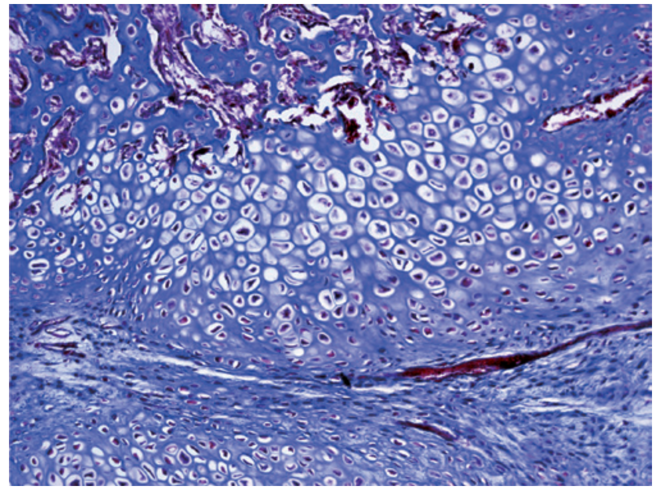

Figure 10. Histological slide of the second week of bone healing process. Chondrocytes, vessels, and abundant connective tissue can be seen. (Hematoxylin/Eosin, 200X).

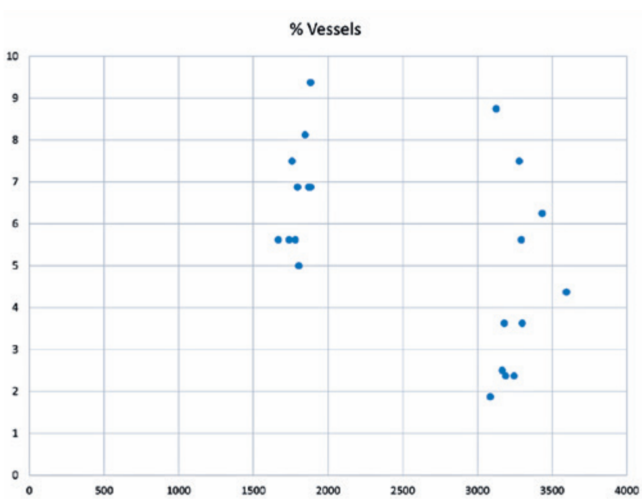

Figure 9. Mean percentage of vessels and its relation to Hounsfield units.

elapsed since the fracture occurred. Initially, there is signs of acute inflammatory process: This stage typically occurs in the first few days after the fracture and is characterized by the presence of inflammatory cells, such as neutrophils and macrophages, in the fracture site[18].

Then, there is the formation of a soft callus, around one to two weeks after the fracture and a callus made of cartilage and collagen is seen. The third phase is the hard callus stage (woven bone), which happens three to four weeks after the fracture, here, ossification of the soft callus can already be seen. Finally, the last step is the remodeling phase, which can take months after the fracture and there a reshaping of the bone tissue–the callus is replaced by newformed bone. During bone healing, blood vessels and bone-forming cells, such as osteoblasts and osteoclasts, as well as the organization and alignment of the bone tissue are also observed in the histological evaluation. As the healing process progresses, the bone callus gradually becomes denser as it is replaced by new bony tissue[18].

In the context of bone healing, HU can be used to monitor the density of the bone tissue at the site of a fracture during the healing process. During the early stages of bone healing, the bone tissue at the fracture site is less dense than the surrounding healthy bone tissue. This is because the bone callus that forms during the healing process is initially made of soft tissue, such as cartilage and collagen fibers, which have lower HU than mature bone tissue[5,10]. To highlight the importance of the HU measurement, a recent study showed that it can be used as a predictor for nonunions in distal tibia fractures[19].

Bone histomorphometry can provide information about bone turnover, mineralization, and remodeling, which are important processes for maintaining bone strength and integrity. By analyzing bone tissue samples, it is possible to observe the degree of mineralization, and the composition of bone tissue. This information can be used to identify changes in bone health and to monitor the effectiveness of treatments for bone disorders such as osteoporosis, thus it is a commonly used method of bone analysis[2].

In our study, fracture healing was assessed by comparing the characteristics of the ROI/HU and histological analysis. It was observed that the ROI/HU findings were compatible with the histomorphometric analysis, in which the bones showed an inverse proportional relation between HU, collagen content, and chondrocytes, while it showed a proportional relation with calcium and intermediate connective tissue. To our knowledge this is the first study to correlate the radiological analysis of HU with histomorphometric findings.

Conclusion

Our study demonstrated that the use of the ROI technique and measurement in HU on digital radiographs was corroborated by histological findings in a fractured bone, and thus safe and reliable method for monitoring bone healing.

Authors' contributions: Correlation between the region of interest in digital radiography, Hounsfield units, and histological maturation on Wistar rats submitted to tibial fracture: EOCP *(https://orcid.org/0000-0002-9557-8328) Conceived and planned the activities that led to the study, performed the experiment, collected the data, interpreted the results, reviewed the manuscript draft and approved the final version; LASP *(https://orcid.org/0000-0002-2756-1794) Performed the statistical analysis, interpreted the results of the study, performed the bibliographic review, created the first draft of the manuscript, formatted the article, participated in the review process and approved the final version; MAB *(https://orcid.org/0000-0001-7988-1071). Performed the bibliographic review, interpreted the results, analyzed the histological images, reviewed the manuscript draft and 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

Artificial intelligence in foot and ankle pathology: Can large language models replace us?

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Abstract

Objective: Determine if large language models (LLMs) provide better or similar information compared to an expert trained in foot and ankle pathology in various aspects of daily practice (definition and treatment of pathology, general questions).

Methods: Three experts and two artificial intelligent (AI) models, ChatGPT (GPT-4) and Google Bard, answered 15 specialty-related questions, divided equally among definitions, treatments, and general queries. After coding, responses were redistributed and evaluated by five additional experts, assessing aspects like clarity, factual accuracy, and patient usefulness. The Likert scale was used to score each question, enabling experts to gauge their agreement with the provided information.

Results: Using the Likert scale, each question could score between 5 and 25 points, totaling 375 or 75 points for evaluations. Expert 2 led with 69.86%, followed by Expert 1 at 68.53%, ChatGPT at 64.80%, Expert 3 at 58.40%, and Google Bard at 54.93%. Comparing experts, significant differences emerged, especially with Google Bard. The rankings varied in specific sections like definitions and treatments, highlighting GPT-4's variability across sections. The results emphasize the differences in performance among experts and AI models.

Conclusion: Our findings indicate that GPT-4 often performed comparably to or even better than experts, particularly in definition and general question sections. However, both LLMs lagged notably in the treatment section. These results underscore the potential of LLMs as valuable tools in orthopedics but highlight their limitations, emphasizing the irreplaceable role of expert expertise in intricate medical contexts.

Evidence Level: III, observational, analytics.

Keywords: Large language models; Artificial intelligence; Foot and ankle; ChatGPT; Google Bard; Generative AI.

Introduction

The Turing test, proposed by Alan Turing in 1950, evaluates a machine's intelligence by observing whether it can generate responses indistinguishable from those provided by a human[1]. With the emergence of large language models (LLMs), such as ChatGPT (GPT-4) or Google Bard, demonstrating a significant ability to understand or coherently generate medical responses, Turing's work has gained paramount importance. These models have become powerful tools in various fields, including medicine[2].

The term artificial intelligence (AI) was first described by McCarthy et al. in 1955 when they referred to AI as "the science and engineering of making intelligent machines." They believed these machines would be capable of performing

Study performed at the Hospital Italiano de Buenos Aires. Ciudad Autónoma de Buenos Aires, Argentina.

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tasks traditionally considered exclusive to humans, with the primary limitation being the speed and memory of programs. Jerrold S. Maxmen, a psychiatry professor at Columbia University, predicted that AI would usher in the "post-medical era" for the 21st century, describing the shift as "possible, inevitable, and desirable"[(3)].

Artificial intelligence is now regarded as the primary potential catalyst of the fourth industrial revolution, following the steam engines of the 1760s, the electricity and oil revolution of the 1870s, and computers of the 1970s[(4)].

GPT-4 and Google Bard represent the latest introductions in AI and have quickly found their place in healthcare services. Both models employ a hybrid language format that includes supervised learning and unsupervised or reinforcement learning with human feedback. They can provide an overview of existing literature on a specific topic within our specialty[(5-6)].

GPT-4 has been tested to pass high-level exams such as the United States Medical Licensing Examination (USMLE)[(7)] and the American Board of Orthopedic Surgery (ABOS)[(8)] exam. While there is no doubt about the high potential and capabilities of various AI tools like GPT-4 or Google Bard, there are several concerns regarding their application in medicine, particularly in orthopedics, and even more specifically in a subspecialty foot and ankle pathology.

The objective of this study is to examine the ability of LLMs to respond to medical queries related to foot and ankle pathology. The information provided by GPT-4/Google Bard will be compared and evaluated by various experts from the foot, ankle, and leg society. The accuracy, timeliness, and relevance of the information provided by GPT-4/Google Bard will be assessed.

Methods

In November 2023, three experts from Argentina Society of Medicine and Foot and Leg Surgery (SAMeCiPP) and two LLMs (GPT-4 and Google Bard) responded to 15 specialty-related questions. Five questions were definitions related to the specialty, five were treatments that should be performed based on a specific pathology, and the remaining five were general information queries. The questions are detailed in Figure 1. Five tests were conducted (3 experts/2 LLMs). The 15 responses were coded and redistributed into five new tests for evaluation. Five more experts from SAMeCiPP evaluated the responses from the experts and the LLMs without knowing to whom each question belonged (Table 1a). The instructions given to the experts and the LLMs are detailed in Table 1b.

For each response, five aspects were evaluated: 1) the provided information is comprehensive; 2) the provided response is confusing; 3) there are factual errors in the provided information; 4) the information is up-to-date; and 5) the response is a good source of information for the patient. The maximum possible score for each question was 25 points, and the minimum was 5. Each question was scored according to the Likert scale (Table 2)[(9)]. This scale allows the evaluator's experts to express their agreement or disagreement with provided statements or assertions, assigning a numerical value indicating their degree of agreement or disagreement.

SECTION 1	DEFINITIONS	Total Likert scale points per question
	1. Define plantar fasciitis	25
	2. Define hallux valgus	25
	3. Define Freiberg disease	25
	4. Define Morton´s neuroma	25
	5. Define hallux rigidus	25
SECTION 2	**TREATMENT**	
	6. In the case of recurrent hallux valgus deformity after primary surgery, discuss revision options and surgical considerati	25
	7. In a patient presenting with central metatarsalgia that does not respond to medical treatment with a disharmonic metatarsal formula, what medical treatment would be indicated?	25
	8. What should be the position of the hallux in its arthrodesis?	25
	9. How are stress fractures of the fifth metatarsal treated	25
	10. Analyze current and emerging options for Achilles tendon plastic surgery, including stem cell therapies and tissue engineering	25
SECTION 3	**GENERAL QUERIES**	
	11. What is the Bohler's angle used for?	25
	12. What is the Sanders classification for calcaneal fractures like?	25
	13. What is the main advantage of surgical treatment of the Achilles tendon compared to conservative treatment?	25
	14. What nerve is trapped in tarsal tunnel syndrome and how is the diagnosis of this condition made?	25
	15. What neurological structure is at risk when performing intramedullary screw fixation for fractures of the fifth metatars	25
TOTAL EXAM		375

Figure 1. Questions for experts and LLMs with the Likert scale score for each question and the total exam.
LLMs: Large language models.

Determine if the LLMs provide better or similar information compared to an expert trained in foot and ankle pathology in various aspects of daily practice (definition and treatment of pathology, general questions).

Results

The maximum possible score for each question was 25 points, and the minimum was 5, according to the Likert scale. Thus, the highest possible total score for each evaluation was 375 points, and the minimum was 75. The score obtained by each expert is described in Table 3, along with the percentage of the total possible points.

Expert 2 (E2) achieved the highest value from external evaluators, scoring 69.86% of the total score (269/375). Expert 1 (E1) scored 68.53%, representing 257/375, GPT-4 scored 64.80%, representing 243/375, Expert 3 (E3) scored 58.40%, representing 219/375, and Google Bard scored 54.93%, representing 206/375 (Figure 2). The results were compared among the evaluator's experts and between the experts and LLMs, as detailed in Table 3.

In the comparative analysis among the experts, no significant differences were observed between E1 and E2 (z-stat: -0.395, p-value: 0.692). However, notable differences were identified in the overall exam scores when comparing E1 with E3 (z-stat: 2.882, p-value: 0.004) and E2 with E3 (z-stat: -3.274, p-value: 0.001). No significant differences were found in the overall exam score between E1 and GPT-4 (z-stat: 1.084, p-value: 0.278) nor between E2 and GPT-4 (z-stat: 1.479, p-value: 0.139) when comparing the results between the experts and the LLMs. No significant differences were observed when comparing E3 with GPT-4 (z-stat: -1.802, p-value: 0.072). On the other hand, significant differences were found in all cases (E1 vs Bard: z-stat: 3.832, p-value: 0.0001; E2 vs Bard: z-stat: 4.222, p-value: 0.0001; E3 vs Bard: z-stat: 0.958, p-value: 0.338; GPT-4 vs Bard: z-stat: 2.756, p-value: 0.006) when comparing the results of all experts with Google Bard. These results suggest notable discrepancies in performance between the experts and Google Bard, while no significant differences were evident between the experts and GPT-4 in the overall exam.

If each set of questions (definition, treatment, and general) were considered separately, the maximum score (5 questions per set) would be 125 points, and the minimum score would be 25 points.

In the definitions section (Table 4), the same analysis was conducted for the entire exam. The total scores were compared (Figure 3), and the percentage of each exam between the experts and LLMs.

Table 1. Distribution of questions among evaluators to avoid biases in the exam evaluation

	Expert 1 Exam	Expert 2 Exam	Expert 3 Exam	ChatGPT Exam	Google Bard Exam
A	15 questions	15 questions	15 questions	15 questions	15 questions
	15 answers	15 answers	15 answers	15 answers	15 answers
	5 Q&A definitions	5 Q&A definitions	5 Q&A definitions	5 Q&A definitions	5 Q&A definitions
	5 Q&A treatment	5 Q&A treatment	5 Q&A treatment	5 Q&A treatment	5 Q&A treatment
	5 Q&A generalities	5 Q&A generalities	5 Q&A generalities	5 Q&A generalities	5 Q&A generalities
B	**Exam evaluator 1**	**Exam evaluator 2**	**Exam evaluator 3**	**Exam evaluator 4**	**Exam evaluator 5**
	15 answers	15 answers	15 answers	15 answers	15 answers
	3 definitions answers	3 definitions answers	3 definitions answers	3 definitions answers	3 definitions answers
	2 definitions answers	2 definitions answers	2 definitions answers	2 definitions answers	2 definitions answers
	3 treatment answers	3 treatment answers	3 treatment answers	3 treatment answers	3 treatment answers
	2 treatment answers	2 treatment answers	2 treatment answers	2 treatment answers	2 treatment answers
	3 generalities answers	3 generalities answers	3 generalities answers	3 generalities answers	3 generalities answers
	2 generalities answers	2 generalities answers	2 generalities answers	2 generalities answers	2 generalities answers

Table 2. Likert scale for the evaluation of 15 questions. Each question had a maximum score of 25 points and a minimum of 5 points.

1. The provided information is comprehensive	1. Strongly disagree	2. Disagree	3. Neither agree nor disagree	4. Agree	5. Strongly agree
2. The provided response is confusing	1. Strongly disagree	2. Disagree	3. Neither agree nor disagree	4. Agree	5. Strongly agree
3. There are factual errors in the provided information	1. Strongly disagree	2. Disagree	3. Neither agree nor disagree	4. Agree	5. Strongly agree
4. The information is up-to-date	1. Strongly disagree	2. Disagree	3. Neither agree nor disagree	4. Agree	5. Strongly agree
5. The response is a good source of information for the patient	1. Strongly disagree	2. Disagree	3. Neither agree nor disagree	4. Agree	5. Strongly agree

Table 3. Comparative table between the experts and LLMs (total exam). The comparative p-values where significant differences exist are highlighted.

	Total points	Percentage of exam	p-value < 0.05
Expert 1 (E1)	257 / 375	68.53 %	vs E2 = 0.692 **vs E3 = 0.004** vs CG = 0.578 **vs GB = 0.001**
Expert 2 (E2)	269 / 375	69.86 %	**vs E3 = 0.001** vs CG = 0.139 **vs GB = 0.001**
Expert 3 (E3)	219 / 375	58.40 %	vs CG = 0.578 **vs GB = 0.038**
ChatGPT (CG)	243 / 375	64.80 %	**vs GB = 0.006**
Google Bard GB)	206 / 375	54.93 %	

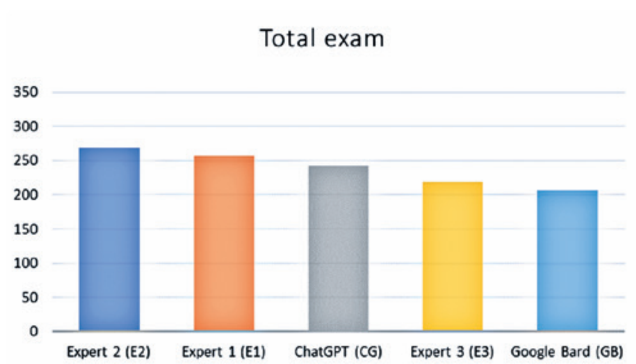

Figure 2. Likert scale scores for each expert and LLMs on the total exam. The maximum score is 375.

Table 4. Comparative table between the experts and LLMs (definitions section). The comparative p-values where significant differences exist are highlighted.

	Total points	Percentage of exam	p-value < 0.05
Expert 1 (E1)	87 / 125	69.6 %	vs E2 = 0.265 **vs E3 = 0.036** vs CG = 0.891 vs GB = 0.347
Expert 2 (E2)	95 / 125	76 %	**vs E3 = 0.001** vs CG = 0.203 **vs GB = 0.038**
Expert 3 (E3)	71 / 125	56.8 %	vs CG = 0.578 vs GB = 0.244
ChatGPT (CG)	86 / 125	68.8 %	vs GB = 0.422
Google Bard (GB)	80 / 125	64 %	

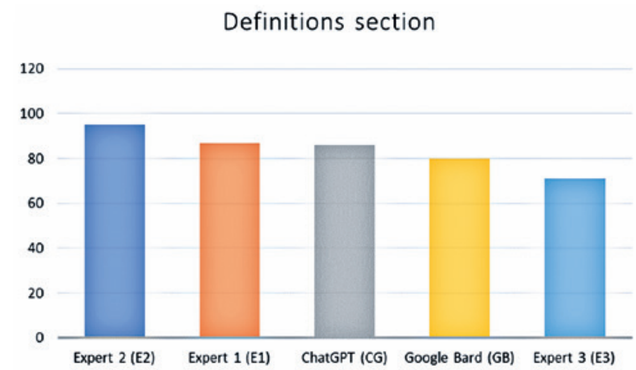

Figure 3. Likert scale scores for each expert and LLMs in the definitions section. The maximum score is 125.

No significant differences were observed between E1 and E2 (z-stat: -1.137, p-value: 0.256) when comparing the results in the definitions section among the experts. However, significant differences were evident between experts and E3, who received the lowest evaluation (E1 vs E3: z-stat: 2.098, p-value: 0.036; E2 vs E3: z-stat: 3.214, p-value: 0.001). No significant differences were found in any of the cases during the definitions section (E1 vs GPT-4: z-stat: 0.137, p-value: 0.891; E1 vs Bard: z-stat: 0.940, p-value: 0.347; E2 vs GPT-4: z-stat: 1.273, p-value: 0.203; E2 vs Bard: z-stat: 2.070, p-value: 0.038; E3 vs GPT-4: z-stat: 1.963, p-value: 0.050; E3 vs Bard: z-stat: 1.164, p-value: 0.244) when evaluating the experts against the LLMs. These results indicate consistency between the experts and LLMs in the definitions section without observing statistically different performances in any of the cases.

In the questions related to treating various pathologies in the specialty, the results were evaluated similarly to the previous section (Figure 4 and Table 5). When comparing the results among the experts, there were no differences between E1 and E2, who remain the experts with the best assessment (z-stat: 0.592, p-value: 0.554). However, there were differences between both in relation to E3 (E1 vs E3: z-stat: 2.622, p-value: 0.009; E2 vs E3: z-stat: 2.041, p-value: 0.041) and to both LLMs (E1 vs GPT-4: z-stat: 4.116, p-value: 0.0001; E1 vs Bard: z-stat: 5.800, p-value: 0.0001; E2 vs GPT-4: z-stat: 1.774, p-value: 0.076). Lastly, there were no differences between E3 and GPT-4 (E3 vs GPT-4: z-stat: 1.536, p-value: 0.125) but there were with Google Bard (z-stat: 3.291, p-value: 0.001). In this section, when comparing both LLMs, they behaved similarly with no differences in their results (z-stat: 1.774, p-value: 0.076).

The final analysis focuses on general queries. Figure 5 presents the results obtained for each evaluator. Contrary to previous sections, in this case, GPT-4 achieved the best performance, while Google Bard, which had received a less favorable evaluation in the two previous, managed an improved score. This shift in performance underscores the

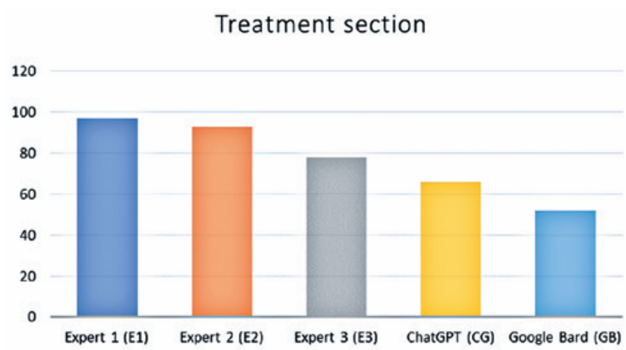

Figure 4. Likert scale scores for each expert and LLMs on the treatment section. The maximum score is 125.

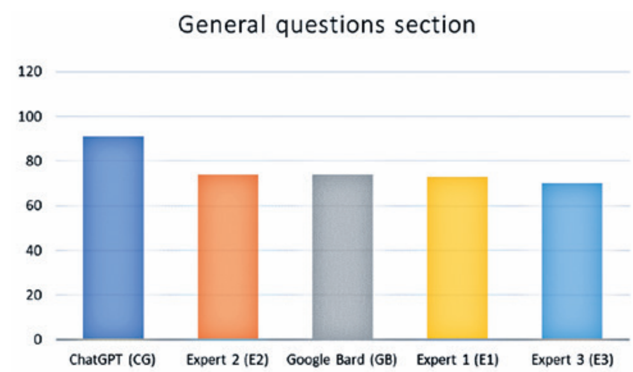

Figure 5. Likert scale scores for each expert and LLMs on the general questions section. The maximum score is 125.

Table 5. Comparative table between the experts and LLMs (treatment section). The comparative p-values where significant differences exist are highlighted.

	Total points	Percentage of exam	p-value < 0.05
Expert 1 (E1)	97 / 125	77.6 %	vs E2 = 0.554 **vs E3 = 0.009** **vs CG = 0.001** **vs GB = 0.001**
Expert 2 (E2)	93 / 125	74.4 %	**vs E3 = 0.041** **vs CG = 0.001** **vs GB = 0.001**
Expert 3 (E3)	78 / 125	62.4 %	vs CG = 0.125 **vs GB = 0.001**
ChatGPT (CG)	66 / 125	52.8 %	vs GB = 0.076
Google Bard (GB)	52 / 125	41.6 %	

Table 6. Comparative table between the experts and LLMs (general questions section). The comparative p-values where significant differences exist are highlighted.

	Total points	Percentage of exam	p-value < 0.05
Expert 1 (E1)	73 / 125	58.4 %	vs E2 = 0.898 vs E3 = 0.701 **vs CG = 0.017** vs GB = 0.898
Expert 2 (E2)	74 / 125	59.2 %	vs E3 = 0.609 **vs CG = 0.023** vs GB = 1
Expert 3 (E3)	70 / 125	56%	**vs CG = 0.006** vs GB = 0.609
ChatGPT (CG)	91 / 125	72.8 %	vs GB = 0.023
Google Bard (GB)	74 / 125	59.2 %	

variability of results between thematic sections and suggests that the performance of the evaluators, whether experts or LLMs, can vary depending on the specific nature of the questions and topics addressed. As seen in Table 6, significant differences were observed in favor of GPT-4 against the other four (GPT-4 vs E1: z-stat: -2.396, p-value: 0.017; GPT-4 vs E2: z-stat: -2.270, p-value: 0.023; GPT-4 vs E3: z-stat: -2.774, p-value: 0.006; GPT-4 vs Bard: z-stat: -2.270, p-value: 0.023) when comparing the results. When comparing the results among the experts themselves in this case, there were no differences between them, nor were there differences between the experts and Google Bard.

Discussion

The objective of the study was to evaluate the performance of GPT-4 and Google Bard in providing answers to complex questions about foot and ankle pathology and compare the results with the experts, all of whom are full members of the association.

Our study reveals that faced with 15 specific questions regarding leg, ankle, and foot pathology, a subspecialty of orthopedics and traumatology, GPT-4 demonstrates comparable behavior and, in some cases, even superior to experts with experience in this area. In contrast, Google Bard does not exhibit such outstanding performance, which aligns with previous findings in the literature that have compared both LLMs[10].

The ability of GPT-4 and Google Bard to answer questions in this subspecialty is evident in their capacity to understand and generate coherent responses. These LLMs have demonstrated relative competence in interpreting medical queries. However, it is crucial to note that their knowledge stems from previous data, not from practical experience or direct clinical interaction[11].

This assertion is supported by analyzing the different thematic sections of the questionnaire. In the definitions section, GPT-4 and Google Bard exhibited behaviors comparable to those of experts. Similarly, in the general questions section, it was observed that GPT-4's performance even surpassed that of the experts, while Google Bard's performance improved compared to the other two sections. However, in the treatment section, the performance of both LLMs was notably inferior to that of the experts, highlighting that, for the definition of surgical treatments, LLMs might not be the most suitable source of information[12-13].

Although these LLMs possess extensive knowledge, their lack of clinical context and direct experience could limit their ability to handle specific cases or complex clinical situations. As noted by Lopes et al., the accurate interpretation of medical data often requires a deep understanding of the clinical context, something these LLms might lack [14].

The efficacy of LLMs in this field is also influenced by the quality and quantity of available training data[15]. Moreover, constant updates in medical research can affect their ability to stay updated.

Despite these limitations, it is evident that AI, represented by GPT-4 and Google Bard, can be a valuable tool in the orthopedics and traumatology field, providing general information and initial support. However, consultation with an expert remains essential for more detailed evaluations and informed surgical decisions.

Both LLMs have the potential to improve access to healthcare for patients. However, it is important to remember that these technologies are not flawless and cannot replace specialized medical personnel. Medical consultations with LLMs may be prone to errors and may not always provide accurate or updated information[7]. It is crucial for the medical community to use these medical applications as a complementary tool to the healthcare provided by expert doctors.

Conclusion

A detailed analysis of the thematic sections of the questionnaire reveals that both GPT-4 and Google Bard demonstrated notable skills in definitions and general questions, even equating and surpassing, in some cases, the performance of experts. However, this efficacy significantly decreased in the treatment section, where both LLMs exhibited considerably inferior performance compared to experts.

This finding underscores the importance of considering the limitations of the LLMs, especially in clinical contexts where the precise definition of surgical treatments requires deeper knowledge and practical experience that these LLMs currently lack. It is crucial to recognize that, despite their capabilities, LLMs cannot completely replace the expertise and clinical judgment of healthcare professionals in specific and complex situations.

These results emphasize the need for effective collaboration between AI and clinical experts to achieve a more comprehensive and accurate approach to medical decision-making.

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Original Article

Comparison of pre-and postoperative clinical-functional results of total ankle arthroplasty for arthrosis treatment

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Abstract

Objective: Compare the pre-and postoperative clinical-functional results of total ankle arthroplasty (TAA) to treat ankle arthrosis applying the American Orthopaedic Foot and Ankle Society (AOFAS) score, the Foot and Ankle Outcome Score (FAOS), the Quality of Life Questionnaire (SF-36), and the Visual Analog Scale of Pain (VAS).

Methods: A retrospective clinical study was conducted, including 15 patients who were submitted to TAA to treat ankle arthrosis.

Results: The t-student test was used to compare the AOFAS score and the FAOS between the pre-and postoperative periods. The results showed a significant increase; the AOFAS increased from 25.8 to 79.8, and the FAOS increased from 7.2 to 69.8. When correlating the VAS and the FAOS, it was noted that the higher the FAOS in the postoperative, the lower the VAS and vice versa. When performing the positive correlation between the SF-36 (mental health) and the FAOS (quality of life), it was observed that the higher the SF-36 score, the higher the FAOS score.

Conclusion: Total ankle arthroplasty is a safe option with better results regarding limb functionality for patients in advanced stages of ankle arthrosis, improving the quality of life of these patients.

Level of Evidence IV; Therapeutic Studies; Case Series.

Keywords: Arthroplasty, replacement, ankle; Osteoarthritis; Ankle.

Introduction

The development of this study was due to the difficulty in solving the complaints of patients with ankle osteoarthritis, which is frequent for foot and ankle surgeons[1-8].

It is known that 1% of the general population develops ankle osteoarthritis due to traumatic or metabolic causes. Osteoarthritis presents with pain, dysfunction, and progressive worsening of gait, and the most common causes are post-traumatic and primary osteoarthritis[1-4, 9,10].

Additionally, in cases of advanced osteoarthritis in patients without angular changes at the ankle level, surgical options involve choices that preserve or not joint movement. Arthrodesis and ankle prosthesis are viable alternatives. Although the initial outcomes of first-generation arthroplasties were not as satisfactory, when compared to the good results obtained with arthrodesis associated with the low cost of the procedure, this is the intervention chosen to treat most cases conducted by foot and ankle surgeons[11-14].

Arthroplasty in large joints is a well-established procedure, prompting a search for total ankle arthroplasty (TTA) improvement.

Evidence shows that TAA preserves joint mobility, improves limb function, reduces pain, and presents high rates of satisfaction among patients. However, the revision rates involving TAA are significantly higher than those observed in arthrodesis; therefore, the procedure of choice remains arthrodesis[5-8]. In selected patients, however, TAA is an excellent alternative for osteoarthritis.

Study performed at the Pontifícia Universidade Católica de Campinas, Departamento de Ortopedia e Traumatologia, Campinas, SP, Brazil.

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Thus, considering the challenge of selecting the appropriate technique to treat patients with osteoarthritis and the advent of less invasive surgical materials and instruments for the ankle joint, arthroplasty has been increasingly integrated into treatment planning(15-18).

This study, therefore, aims to evaluate the functional outcome of patients submitted to TAA. The objective is to contribute to the growing utilization of this surgical alternative in treating osteoarthritis and to provide valuable insights into this procedure for foot and ankle surgeons. In addition, the aim of the study is to compare the pre-and postoperative clinical-functional results of total ankle arthroplasty (TAA) to treat ankle arthrosis applying the American Orthopaedic Foot and Ankle Society (AOFAS) score, the Foot and Ankle Outcome Score (FAOS. The Quality of Life Questionnaire (SF-36) and the Visual Analog Scale of Pain (VAS) were also used to investigate whether there was an improvement in quality of life in the first three postoperative months.

Methods

This study was approved by the Institutional Review Board under the number CAAE 45265021.0.0000.5374. All patients included in the study signed an informed consent form.

Fifteen patients with a mean age of 55.7 years were included, varying between 37 and 72 years old. The selection process was conducted in a private hospital from December 2018 to January 2023. All included patients were arthrosis grade 4 according to the Takakura classification (obliteration of the joint space with complete bone contact), without previous hindfoot and midfoot deformities, with good bone alignment, without indication of osteotomies corrections or intraoperative talonavicular or calcaneocuboid arthrodesis, evaluated with anteroposterior (AP) and profile ankle radiographs with weight-bearing and Saltzman incidence, with a mean preoperative range of motion of 25º plantar flexion and 5º dorsiflexion.

Patients were submitted to TAA to treat ankle arthrosis in a private hospital. Considering that TAA is typically performed exclusively at specialized foot and ankle surgery centers and entails high expenses due to the materials utilized and the technical complexities it presents, the pool of patients eligible for this treatment remains limited.

There was no follow-up loss during the study.

Inclusion criteria

Patients of both sexes diagnosed with ankle osteoarthritis Takakura grade 4, confirmed on AP and profile ankle radiographs with weight-bearing and Saltzman incidence, associated with clinical symptoms such as pain in the ankle region, joint stiffness, and functional ankle limitation.

Exclusion criteria

Patients who did not agree to participate in the study and/or had avascular necrosis of the talus, acute or chronic tibiotarsal joint infection, paralysis, and severe misalignment of the tibia and talus or neurological changes.

Surgical procedure

All patients that met the inclusion criteria were submitted to the laboratory tests. The ankle radiographs for surgical planning with the implant templates followed the standardization: AP and profile ankle radiographs with weight-bearing and Saltzman incidence.

In the initial analysis for indication of arthroplasty, patients were clinically evaluated according to a thorough physical examination in which skin changes, axis deviations of the lower limbs, and the range of motion were observed.

The technique used in TAA was the anterior access route of the ankle in dorsal decubitus, with exsanguination and tourniquet application to the limb. An anterior incision was made in the ankle joint, allowing for identification of the neurovascular bundle situated between the extensor hallucis longus and tibialis anterior tendons.

The talar and tibial components were chosen, according to pre-surgical planning, to restore ankle biomechanics. A STRYKER® INFINITY® total ankle primary prosthesis was used, with a metal vs polyethylene tribological pair (Figures 1 and 2).

It is important to note that there were no complications during surgery.

All patients were submitted to antithrombotic prophylaxis with rivaroxaban 10 mg once daily for 28 days, associated with antibiotic prophylaxis with cephalexin 500 mg every six hours for seven days. The patients wore orthopedic boots until the wound healed, a mean of 14 to 21 days, remaining with no weight-bearing during this period and undergoing motor physiotherapy since the immediate postoperative period. They were reassessed weekly during the first month, in the third and sixth postoperative months, and one year after surgery.

Clinical-functional evaluation

After the inclusion process, a preoperative clinical-functional evaluation of the ankle was performed at the foot and ankle orthopedics and traumatology outpatient clinic. The evaluation lasted approximately 40 minutes and consisted of preoperative consultation and AOFAS and FAOS application. In the third postoperative month, the SF-36 and VAS were applied to evaluate whether there was pain and quality of life improvement. Patients returned to the hospital in the sixth postoperative month for a new postoperative consultation and AOFAS and FAOS reapplication.

All pre-and postoperative analyses were included in the patient's medical records and are part of the institution's foot and ankle service routine.

Considering that the AOFAS authors did not correlate numerical values to the categories excellent, good, regular, and very bad, a generic quality of life questionnaire (SF-36) with categorization evaluated separately, whose final sum

Figure 1. Preoperative radiograph of the right ankle (A-C), image of the surgical access (D), cutting guide fluoroscopy (E), image after surgical cut (F).

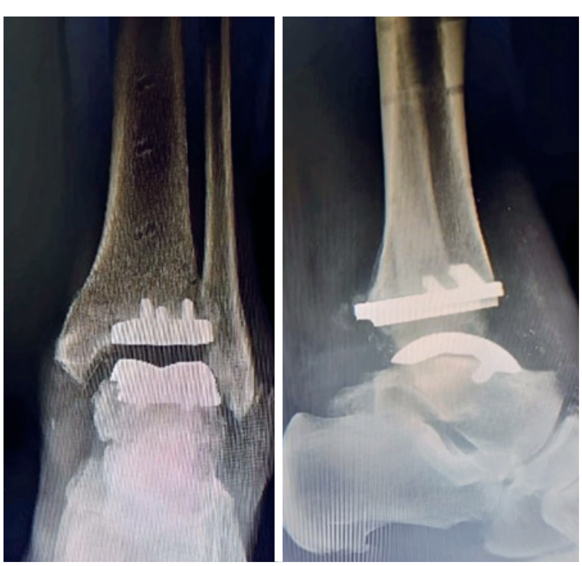

Figure 2. Anteroposterior and profile postoperative radiographs.

ranged from 0 to 100 points (0 = worst and 100 = best)[2,10,19] was used to avoid confusion in the evaluation of the results[2]. Through studies of the scales and after translation and validation of the AOFAS score, it was considered valid and reproducible to evaluate the patients participating in this study regarding clinical-functional aspects[2,20]. Although some authors question the AOFAS score due to its subjectivity and the probability that the interpretation of the results and the perception of the patient's improvement can sometimes vary greatly between physicians and researchers, it remains the consensus research instrument among a wide range of health professionals, used to measure the results about ankle and foot pathologies[21, 22].

The FAOS score is a questionnaire developed to evaluate patient's perceptions regarding ankle and foot pathologies. It comprises five domains: pain, other symptoms, daily living activity, sports and recreation, and quality of life regarding the ankle and foot. The default options are data, and each question is scored from 0 to 4; a population with no changes is calculated for each subscale (100 indicates no symptoms, and 0 indicates extreme symptoms)[2,19,23].

Results

Fifteen patients diagnosed with ankle arthrosis and submitted to TAA were evaluated in our study.

Only one of the patients presented surgical wound dehiscence and, after cleaning and resuture, evolved positively without other complications at one-year postoperative follow-up. There was no need to remove the implant from any patient.

Four questionnaires were used; two were performed in the third postoperative month (VAS, SF-36), and the others were conducted in the pre-and postoperative (AOFAS, FAOS), all to evaluate general quality of life and measure the functionality of the patient's limbs.

Variability is measured by the standard deviation (SD). The closer (or higher) this value is to the mean, the greater the variability. The coefficient of variation (CV) is a statistic that assesses how much the variability represents the mean. Ideally, this index should be as low as possible (< 50%). The confidence interval (CI), sometimes added to and/or subtracted from the mean, shows the mean variation according to a statistical probability.

The mean AOFAS and FAOS showed a statistically significant improvement. In AOFAS, the mean improved from 25.8 to 79.8 (p-value < 0.001), and in FAOS, from 7.2 to 69.8 (p-value < 0.001) (Figure 3). The comparison of AOFAS and FAOS scores in the pre-and postoperative is also shown in Table 1. When the VAS and SF-36 were correlated in the third postoperative month, it was noted that the VAS score was 1.27 and the SF-36 (emotional aspect) 69.8, demonstrating good results shortly after the TAA (Figure 4).

In our study, a descriptive analysis was also performed for age, factors evaluated in the third postoperative month (VAS and SF-36), and Delta (difference in postoperative AOFAS and FAOS scores in relation to preoperative AOFAS and FAOS) both absolutely and relatively (Table 2).

It was evidenced that many factors have low variability due to the CV being less than 50%, demonstrating that the data are heterogeneous. The mean age was 55.7 ± 6.2 years, ranging from 49.5 to 61.9 years, with 95% statistical confidence. The mean AOFAS Delta was 54.0 ± 5.6 (increased by 54.0 points).

When exploring the data using Pearson's correlation to evaluate the degree of correlation between age, VAS, and SF-36 with the AOFAS and FAOS scores, it was noted that when the correlation is positive, it means that as one variable increases its value, the other correlated to it, also increases proportionally. However, if the correlation is negative, the variables are inversely proportional; as one grows, the other decreases, or vice versa.

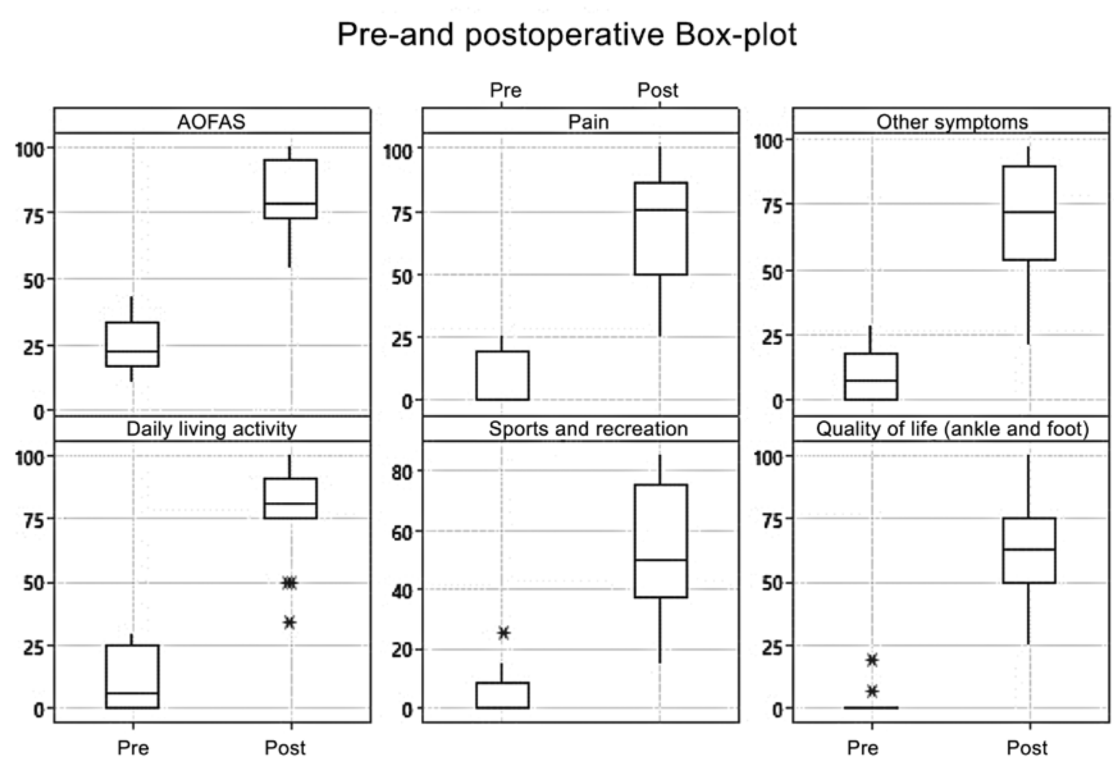

Figure 3. AOFAS scale.

Table 1. Comparison of AOFAS and FAOS

Variables		Mean	Median	SD	CV	Min	Max	n	CI	p-value
AOFAS	Pre	25.8	22	10.5	41%	11	43	15	5.3	< 0.001
	Post	79.8	78	13.2	17%	54	100	15	6.7	
Pain	Pre	7.2	0	10.3	143%	0	25	15	5.2	< 0.001
	Post	69.8	75	21.9	31%	25	100	15	11.1	
Other symptoms	Pre	9.5	7.1	10.7	112%	0	28.6	15	5.4	< 0.001
	Post	68.1	71.4	20.8	30%	21.4	96.4	15	10.5	
Daily living activity	Pre	11.6	5.9	12.3	107%	0	29.4	15	6.2	< 0.001
	Post	77.5	80.9	19.1	25%	33.8	100	15	9.7	
Sports and recreation	Pre	4.6	0	8.1	177%	0	25	12	4.6	< 0.001
	Post	53.8	50	22.2	41%	15	85	12	12.5	
Quality of life (ankle and foot)	Pre	1.7	0	5	300%	0	18.8	15	2.5	< 0.001
	Post	62.9	62.5	22.1	35%	25	100	15	11.2	

AOFAS: American Orthopaedic Foot and Ankle Society; SD: Standard deviation; CV: Coefficient of variation; CI: Confidence interval.

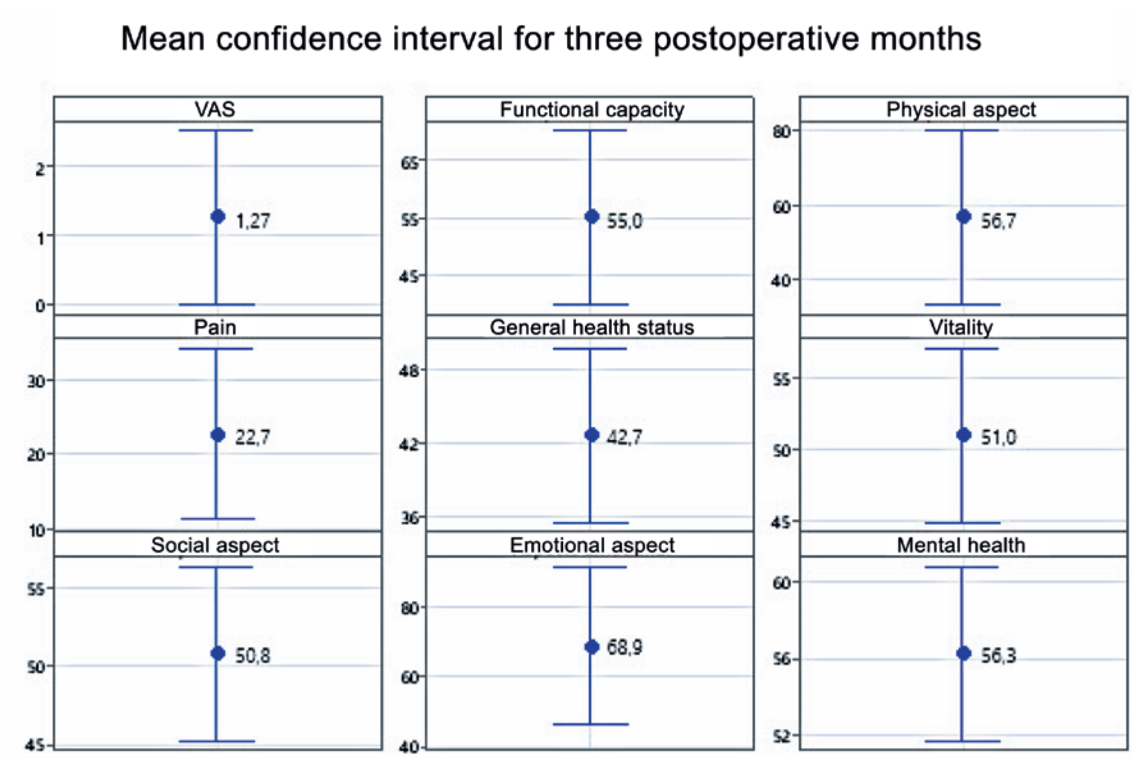

Figure 4. AOFAS comparison in the three postoperative months.

It was concluded that there are some statistically significant correlations, such as between VAS and FAOS (sports) in the postoperative with r = -0.761 (p-value = 0.004). Because the value is negative, the higher the FAOS (sports) score in the postoperative, the lower the VAS and vice versa. It can be classified as a strong correlation.

Similarly, when performing the positive correlation between the SF-36 (mental health) and the FAOS (quality of life) in the postoperative with r = 0.641 (p-value = 0.010), it is clear that the higher the SF-36 (mental health) score, the higher the FAOS (quality of life) score and vice versa (Table 3).

Table 2. Descriptive data for age, AOFAS/FAOS Delta, and three postoperative months

Variables		Mean	Median	SD	CV	Min	Max	n	CI
Age		55.7	55	12.2	22%	37	72	15	6.2
Delta	AOFAS	54	54	11.1	20%	32	76	15	5.6
	Pain	62.6	72.2	18.1	29%	25	86.1	15	9.2
	Other symptoms	58.6	53.6	19.9	34%	21.4	89.3	15	10.1
	Daily living activity	65.9	66.2	17.6	27%	33.8	94.1	15	8.9
	Sports and recreation	49.2	50	26.5	54%	0	85	12	15
	Quality of life (ankle and foot)	61.3	62.5	21.2	35%	25	100	15	10.7
Three postoperative months	VAS	1.27	0	2.25	178%	0	6	15	1.14
	Functional capacity	55	55	27.3	50%	0	95	15	13.8
	Physical aspect	56.7	75	41.7	74%	0	100	15	21.1
	Pain	22.7	20	20.5	91%	0	60	15	10.4
	General health status	42.7	45	12.7	30%	10	60	15	6.4
	Vitality	51	50	10.9	21%	20	70	15	5.5
	Social aspect	50.8	50	10	20%	37.5	75	15	5.1
	Emotional aspect	68.9	100	40.8	59%	0	100	15	20.6
	Mental health	56.3	60	8.1	14%	44	68	15	4.1

AOFAS: American Orthopaedic Foot and Ankle Society; SD: Standard deviation; CV: Coefficient of variation; CI: Confidence interval; VAS: Visual Analog Scale of Pain.

Table 3. Correlation of age, VAS, and SF-36 with AOFAS and FAOS

Variables			Age	VAS	Functional capacity	Physical aspect	Pain	General health status	Vitality	Social aspect	Emotional aspect	Mental health
AOFAS	Pre	r	0.002	-0.178	0.122	0.166	-0.149	0.194	0.039	-0.261	0.256	0.437
		p-value	0.995	0.525	0.666	0.555	0.596	0.488	0.89	0.347	0.357	0.103
	Post	r	-0.151	-0.419	0.283	0.204	0.142	0.065	-0.262	-0.134	0.072	0.156
		p-value	0.59	0.12	0.307	0.466	0.613	0.817	0.345	0.633	0.8	0.578
FAOS Pre	Pain	r	0.252	-0.063	0.299	0.491	-0.584	-0.621	-0.078	-0.255	0.289	0.423
		p-value	0.364	0.823	0.279	0.063	0.022	0.014	0.783	0.359	0.296	0.116
	Other symptoms	r	0.283	0.131	0.179	0.305	-0.555	-0.465	-0.077	-0.14	0.163	0.525
		p-value	0.307	0.642	0.523	0.268	0.032	0.081	0.786	0.62	0.562	0.045
	Daily living activity	r	0.377	0.036	0.477	0.156	-0.5	-0.326	0.06	0.257	0.071	0.47
		p-value	0.166	0.898	0.072	0.579	0.058	0.235	0.831	0.354	0.803	0.077
	Sports and recreation	r	0.295	0.667	-0.15	-0.165	0.1	-0.066	0.071	-0.357	-0.194	-0.046
		p-value	0.286	0.007	0.595	0.556	0.723	0.816	0.803	0.192	0.489	0.87
	Quality of life (ankle and foot)	r	0.113	0.514	0.115	0.318	-0.352	-0.111	0.049	-0.142	0.2	0.121
		p-value	0.689	0.05	0.684	0.248	0.199	0.695	0.862	0.614	0.475	0.667
FAOS Post	Pain	r	0.129	-0.578	0.433	0.464	-0.365	-0.168	-0.114	-0.126	0.318	0.656
		p-value	0.648	0.024	0.107	0.081	0.182	0.548	0.686	0.654	0.249	0.008
	Other symptoms	r	-0.096	-0.471	0.162	0.256	-0.133	0.187	-0.029	-0.016	0.2	0.451
		p-value	0.735	0.076	0.564	0.357	0.636	0.505	0.917	0.954	0.474	0.092
	Daily living activity	r	-0.017	-0.553	0.541	0.334	-0.194	-0.02	0.071	0.098	0.132	0.502
		p-value	0.951	0.033	0.037	0.224	0.488	0.943	0.803	0.727	0.64	0.057
	Sports and recreation	r	-0.309	-0.761	0.5	0.395	0.063	0.129	-0.108	0.405	0.176	0.366
		p-value	0.329	0.004	0.098	0.204	0.845	0.688	0.738	0.191	0.584	0.242
	Quality of life (ankle and foot)	r	-0.067	-0.469	0.307	0.433	-0.387	-0.363	-0.345	-0.078	0.164	0.641
		p-value	0.811	0.078	0.266	0.107	0.154	0.183	0.208	0.783	0.559	0.01

AOFAS: American Orthopaedic Foot and Ankle Society; FAOS: Foot and Ankle Outcome Score; VAS: Visual Analog Scale of Pain.

Discussion

Total ankle arthroplasty has been increasingly used to treat osteoarthritis due to lower failure rates and better results. However, the literature on this procedure remains heterogeneous, with great variability in the outcomes notification[(24)].

Fourth-generation arthroplasties, such as those performed by the foot and ankle group at the Pontifícia Universidade Católica-Campinas, São Paulo, Brazil, are characterized by the low profile and easy intraoperative radiographic control, allowing the surgery to proceed with precision and be reproducible among surgeons[(15-16)].

The abovementioned characteristics were decisive in defining the type of prosthesis used in this study. Although this model has been used internationally since 2013, the foot and ankle group at the Pontifícia Universidade Católica-Campinas pioneered its use in Brazil. The main reasons for choosing this model were the clinical and radiological results demonstrated in international studies, which led patients in many other countries to opt for arthroplasty to treat ankle arthrosis[(17)].

The complication rates and revisions in ankle prostheses were high, and with the development of implants with fixation in the tibia and talus through pegs, there was a decrease in the shear effect and consequent components loosening[(16)]. Studies have shown a revision rate of 3% to 10%, associated with loosening components and infections[(18,25,26)].

In some studies, the scores that evaluated the patient's ankle function recovery and quality of life confirm a statistically significant improvement, as demonstrated in our study through AOFAS analysis[(18,25-27)].

Shih et al.[(24)], in their meta-analysis, demonstrated an improvement in the AOFAS score in the group where the ankle prosthesis was implanted. Rushing et al.[(18)], in turn, evaluated 55 ankles in a 43-month follow-up period, with a prosthesis-survival rate of 97% and a revision rate of 1.8%, more detailed results when compared to the abovementioned study. A larger sample allows for a more complete analysis; however, it does not invalidate the findings of this study. Saito et al.[(16)] reported a revision surgery rate of 4.7% at a 25-month follow-up with a sample of 64 patients, similar to the rates observed for other implants.

Meanwhile, the United Kingdom National Joint Registry noted that only 1% of cases required revision of the INFINITY® prosthesis at a 14-month follow-up[(9,16-18,25,26)]. In Latin America, a 2020 study by Nery et al.[(21)] reported successful results in 26 patients submitted to arthroplasty using INFINITY® prosthesis, with a 100% survival rate in the first year of follow-up similar to the result found in our study. However, our study evaluated a smaller sample with a similar follow-up time.

Prostheses with fluoroscopic navigation increase the accuracy of postoperative results regarding implant alignment. In 2018, King et al.[(15)] found a 1.5° deviation from the 90° alignment to the anatomical tibia axis in a cohort of 20 patients with a 24-month follow-up. This deviation allows a homogeneous distribution of body weight-bearing, contributing to the preservation of the positioning of the tibial and talar components of the prosthesis. Similarly, Saito et al.[(16)] reported improvement in tibiotalar coronal alignment using a fluoroscopically navigated prosthesis, as shown by the prosthesis maintenance. These results are consistent with those observed in this evaluation.

TAA Indications

Total ankle arthroplasty is indicated to treat degenerative joint disease of the tibiotalar joint caused by trauma, osteoarthritis, and rheumatoid arthritis[(28)].

Saltzman et al., in their study, reported the main causes of ankle arthritis in order of frequency: post-traumatic (63.9%), primary osteoarthritis (27.4%), rheumatoid arthritis (5.0%), and all others (3.7%). Among the participants included in their study, 4.4% were smokers, and 9.0% had diabetes[(29)].

Contraindications of TAA

Contraindications related to TAA include patients with osteoporosis, smokers, diabetes mellitus, immunosuppressed, suffering from neurological disease, vascular disease, age over 50 years, severe misalignment, instability, and avascular necrosis of the talus[(29)]. The absolute contraindications refer to patients with active infection, Charcot's neuroarthropathy, and peripheral vascular disease[(29)].

TAA durability

The implant's durability is closely related to the degree of arthrosis of the patient, the type of implant, the surgical technique, and the surgeon's experience.

There is evidence in the literature that patients with moderate alterations are better candidates for TAA concerning implant durability when compared to patients with severe alterations. As for the type of implant used, the superiority of second-and third-generation and fixed-bearing implants has been noted, with a 95.6% survival rate over mobile bearing (89.4%)[(30)]. Regarding the patient's age, it was observed that survival was higher in older people who underwent the revisions more frequently [(30)].

Similarly, Brunner et al.[(31)] contributed data from 10 and 15 years of follow-up demonstrating an alarming drop in survival, of 53.2% and 32.2%, respectively. This suggests that survival projections do not follow a constant failure rate, as stated by Zaidi et al.[(32)]. Instead, survival slows down faster over time.

Mann et al.[(33)], in their 2011 study, reported a mean survival of mobile implants of 9.1 years, with a durability of 90% after ten years.

TAA revision

Byron et al. reported some complications and were classified as technical error (28.15%), joint sinking (16.89%), implant failure (13.28%), aseptic loosening (6.3%), intraoperative fracture (5.67%), wound problems (4.3%), deep infection (1%) and postoperative fracture (0.0001%)(30,34).

The most frequent complication described by Lawton et al.(35) in one of their studies was aseptic loosening, with an adjusted rate of 5.8%, followed by wound (5.4%) and fracture (4.9%). The adjusted reoperation rate without revision was also higher for arthrodesis (12.9% vs 9.5%).

Wood et al.(36) documented a 12% revision rate for a cohort of 200 ankles submitted to TAA with a mean follow-up of 7.3 years. Most patients required revision for aseptic loosening (7%).

Advantage arthrodesis vs total ankle arthroplasty

Lawton et al.(35) reviewed the complications of third-generation TAA implants and reported that the most common complications were aseptic loosening (5.8%), wound complications (5.4%), fracture (4.9%), and deep infection (0.9%).

The most common complications for arthrodesis were wound complications (9.8%), non-union (7.9%), infection (3.6%), and fracture (0.8%)(36).

Studies have shown a compensatory increase in hindfoot and midfoot movement after ankle arthrodesis, which can generate overload and accelerate joint degeneration. Sealey et al. suggest that ankle arthrodesis may accelerate the progression of hindfoot osteoarthritis and midfoot degeneration(37).

In their comparative study between TAA and ankle arthrodesis, Lawton et al.(35) demonstrated that the overall rate of postoperative arthrodesis complications (26.9%) was higher than TAA (19.7%)(36). Among them are wound healing (9.8%), pseudoarthrosis (7.9%), and deep infection (3.6%)(36).

Quality of life (function) after TAA

Although, unlike arthrodesis, TAA is a complex procedure that requires expertise from the foot and ankle surgeon, it preserves ankle function and avoids overload on adjacent joints, which can lead to arthritic changes requiring future arthrodesis(36).

With the maintenance of ankle function, the patient will have a more harmonious gait, with less energy expenditure and maintaining its parameters (speed, length, cadence, and time)(36).

Limitations

Our study has some limitations, such as the small sample size, the one-year follow-up, and the study design not being a comparative or prospective study. This is mainly due to the adoption of a prosthesis that is still unused in the country. Its first implantation in Brazilian territory was reported only in 2019, with access still restricted to Brazilian hospital services and limited indications due to the high cost.

Conclusion

Total ankle arthroplasty is a good option for patients in advanced stages of ankle arthrosis, offering a significant improvement in their quality of life, mainly enhancing pain relief and limb functionality.

Therefore, whenever possible, it is necessary to consider total ankle arthroplasty as a safe option that guarantees better limb functionality.

Authors' contributions: Each author contributed individually and significantly to the development of this article: JAO * (https://orcid.org/0000-0001-9393-2170) Conceived and planned the activity that led to the study, wrote the article, participated in the review process; RGH*(https://orcid.org/0000-0003-3951-8408) Data collection, bibliographic review; MSPC *(https://orcid.org/0000-0002-0758-2547) Formatting of the article, bibliographic review; HDB *(https://orcid.org/0000-0002-1901-3309) Interpreted the results of the study, participated in the review process; AMAP *(https://orcid.org/0009-0003-9972-1245) CDCCF * (https://orcid.org/0000-0003-3522-1076) LGZ *(https://orcid.org/0009-0001-5620-0920) Performed the surgeries; data collection, statistical analysis. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Original Article

Arthroereisis with interference screw in flexible flatfoot, a comparison with the conventional surgical technique

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Abstract

Objective: To evaluate functional results of subtalar arthroereisis with non-conventional implants, as well as their clinical, radiographic, and functional results, comparing them with those of the conventional technique.

Methods: Documentary research consisting of the analysis and review of medical records of six patients, with application of the Orthopaedic Foot and Ankle Score (AOFAS) and Short-Form Health Survey 36 (SF-36) questionnaires and evaluation of pre-and postoperative radiographic results.

Results: Patients achieved satisfactory clinical and functional results, indicated by an improvement in the pitch, kite, Giannestras, and Meary angles analyzed and by comparing the pre-and postoperative periods. There was also an improvement in the AOFAS and SF-36 questionnaire scores postoperatively, suggesting an evolution in the quality of life of patients studied.

Conclusion: Subtalar arthroereisis is a non-invasive surgical procedure that contributes to the clinical improvement of patients. The use of interference screw showed good results, with the advantage of it being a low-cost implant when compared to the conventional ones, which makes the procedure more accessible.

Level of Evidence III; Therapeutic Studies; Case control study.

Keywords: Flatfoot; Subtalar arthroereisis; Interference screw.

Introduction

Flexible flatfoot is a multiplanar deformity prevalent in children and adults, clinically differing according to the age of onset. In children, the main complaint reported by parents is the appearance of the feet[1-2], possibly associated with ligamentous laxity and functional disability. In adults, medial pain is characterized as the main symptom, associated with tendonitis and posterior tibial insufficiency[3]. When conservative treatment is not effective, surgical treatment is debatable, and the best age for its performance is between 8 and 14 years[4].

The main surgical techniques are arthroereisis, calcaneal lateral stretching osteotomy, and triple arthrodesis. Subtalar arthroereisis stands out because it is a minimally invasive procedure in which encouraging results have been demonstrated, with low surgical risk and reversible complications, if any (implants can be removed). Another advantage presented by the technique is the possibility of bilateral approach at the same surgical time, rapid recovery, and load release[5]. In this procedure, an implant positioned in the subtalar joint, within the tarsus, is used in order to limit the excessive pronation of such joint, promoting its inversion, with restoration of the longitudinal plantar arch, as per Highlander and Myerson[3-4].

Currently, there are several types of implants, each with its particular biomechanical properties, such as: cancellous screw with polyethylene-coated head (Pisani screw), synthetic polyethylene implant, Blount staple, 4.5 mm 24–26 mm

Study performed at the Hospital das Clínicas – HC, Ebserh-UFG; Goiânia, GO, Brazil.

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short-thread cancellous screw, depending on the age[6], STAY-peg devices, and bioabsorbable interference screws. New materials are being developed and tested in an attempt to find the ideal implant for arthroereisis. It is known that the cost of materials is still a limiting factor for their use in the treatment of flexible flatfeet, and this study seeks an effective and low-cost alternative.

Methods

This study was approved by the Institutional Review Board under the number CAAE 00777118.5.0000.0033.

This is a retrospective study based on the analysis of six patients treated by the foot and ankle group at Hospital de Urgências de Goiânia – HUGO. Patients underwent subtalar arthroereisis from January 2013 to August 2018, with an average follow-up time of 58 months between surgical treatment and the last clinical evaluation in an outpatient consultation (patient 1: 96 months, patient 2: 60 months, patient 3: 24 months, patient 4: 24 months, patient 5: 96 months, and patient 6: 48 months). Findings were compared to those of three other patients with an average follow-up time of 32 months between surgical treatment and the last clinical evaluation in an outpatient consultation (patient 1: 36 months, patient 2: 24 months, and patient 3: 36 months). Patients with symptomatic flexible flatfoot who had failed conservative treatment and did not require other corrections and concomitant osteotomies were included. Patients undergoing calcaneal osteotomy associated with subtalar arthroereisis, under 10 years of age, and with marfanoid phenotype were excluded. Based on data obtained from medical records, pre-and postoperatively, all participants were submitted to clinical evaluation through the application of the Orthopaedic Foot and Ankle Score (AOFAS) scale for ankle and hindfoot and Short-Form Health Survey 36 (SF-36) quality of life questionnaire, thus allowing the standardization of results.

Data inherent to age, gender, affected side, deformity, symptoms, flexibility, and range of motion of the affected foot were evaluated, as well as the radiographs of functional angles (pitch, kite, Meary, and Giannestras), pre-and pos-toperatively. Data collected will be kept confidential and stored for a period of five years. Then, it will be incinerated according to the guidelines of the Brazilian National Health Council (CNS) resolution n. 196/96.

Patients' profile characterization was performed by means of absolute frequency, relative frequency, mean, and standard deviation. Data normality was verified using the Shapiro-Wilk test. The distribution of patients' profile in the control and intervention groups was tested using Pearson's chi-square test and Student's *t*-test. The comparison of angles before and after intervention was tested using paired *t*-test. The evaluation of deltas between groups was performed using the Mann-Whitney test. Spearman's correlation analysis was applied in order to evaluate the relationship between the delta of the angles in each group. Data were analyzed using the Statistical Package for Social Science (IBM Corporation, Armonk, USA), version 26.0. A level of significance of 5% ($p < 0.05$) was adopted.

The AOFAS scale is an instrument of easy application and comprehension for specific evaluation of the hindfoot and ankle region. It does not require imaging or other tests of greater complexity. The questionnaire consists of nine items distributed in three categories – pain, functional aspects, and alignment, with respective scores of 40, 50, and 10 points, totaling a maximum score of 100 points. For its interpretation, the following averages are used: less than 40 points, poor; 40–60 points, satisfactory; 60–80 points, good; 80–100 points, excellent results.

The SF-36 is a generic instrument for assessing quality of life. It is a multidimensional questionnaire consisting of 36 items encompassed in 8 domains, namely: functional capacity, pain, general health status, physical aspects, social aspects, vitality, emotional aspects, and mental health. The score is obtained in ranges from 0 to 100, with 0 being the worst general state of health and 100, the best general state of health.

Surgical technique was performed with the patient in the supine position under spinal anesthesia, taking all asepsis and antisepsis measures. Exsanguination by tourniquet of the limb to be operated was performed. A 2 cm incision was made in the topography of the tarsal sinus, with dissection of the subcutaneous tissues with a hemostatic forceps to create a path for guide wire passage in the tarsal canal. The guide wire was inserted about 15° perpendicular to the sagittal plane that goes from anterolateral to posteromedial with the aid of fluoroscopy, and the interference screw was introduced into the tarsal sinus according to Figure 1. To confirm the final placement, fluoroscopy was used. The size of the implant was

Figure 1. Patient positioning and interference screw insertion with a guide wire.

tested intraoperatively by measuring the subtalar resistance. As for the prosthesis, on average, it is 8 mm, but it depends on the test (normally, materials contain 6 mm, 8 mm, and 10 mm test options). When using the interference screw, the size is chosen by measuring the fixation site, taking care to avoid looseness in the subtalar screw. If satisfactory, the guidewire is removed.

Surgical wound was sutured with a simple stitch using Nylon 4.0. In the postoperative period, patients had suropodalic cast immobilization for four weeks in a neutral position of the ankle; after cast removal, they started a physiotherapeutic treatment to gain range of motion and proprioception. Patients stand up or walk with the use of orthosis for two weeks, with use of full load permitted from the eighth week on.

Operated feet were classified as satisfactory or unsatisfactory based exclusively on clinical criteria and personal satisfaction with the aid of the scales applied (AOFAS scale for ankle and hindfoot and SF-36 quality of life questionnaire).

All participants were clinically followed up and radiographed at at least two moments in outpatient visits (annual radiographic follow-up).

Results

In the period from 2013 to 2018, six patients were treated with subtalar arthroereisis, totaling 10 feet operated using interference screw. These patients were compared with three patients treated with conventional implants who totaled six feet operated. All patients were followed up on outpatient visits and evaluated radiographically and clinically using the AOFAS scale and the SF-36 questionnaire before and after surgical procedure. At follow-up, all patients underwent radiograph of the operated foot in order to verify the angular correction obtained, as well as possible signs of complications or surgical failure. In preoperative radiographs, the deformity was observed as per Figure 2 and Figure 3. Figure 4 shows an intraoperative fluoroscopy image.

Figure 2. Preoperative radiographs. A. Anteroposterior; B. Profile, C. Axial view of the calcaneus.

Figure 3. Deformity photographs.

The total prevalence of flatfoot in the present study was higher in male patients (nine feet operated) than in female patients (seven feet operated). Mean age obtained was 11.67 ± 0.52 years in the control group and 12.30 ± 1.64 years in the intervention group. Regarding laterality, nine right feet (56.3%) and seven left feet (43.8%) were approached. In the intervention group, there were six right feet (60%) and four left feet (40%); of these, seven in female patients (70%) and three in male patients (30%). Four patients were bilaterally affected (Table 1).

Patients walked without crutches or other support. There was angular improvement in all angles observed. Preoperative anteroposterior talus-first metatarsal angle in the control group was 25.33º ± 5.32º; postoperative, 4.00º ± 2.28º. In the intervention group, findings were 25.50º ± 4.60º preoperatively and 3.40º ± 2.17º postoperatively. Preoperative Meary angle in the control group was 13.67º ± 0.82º; postoperative, 5.00º ± 1.10º. In the intervention group, angles of 16.40º ± 4.30º were found preoperatively, and of 4.60º ± 2.67º postoperatively. Preoperative calcaneal pitch in the control group was 4.67º ± 1.03º; postoperative, 12.00º ± 2.53º. In the intervention group, findings were 4.70º ± 1.64º preoperatively and 10.60º ± 1.90º postoperatively. No skin complications were observed after surgery (Figure 5, Table 2).

Most patients were satisfied with postoperative results, which is evidenced by an increase in the mean score on the AOFAS scale, where, in the preoperative period, an average of 69.3 points was obtained, while in the postoperative period the average was 87.3 points out of the total score of 100 points (Figure 6)[7].

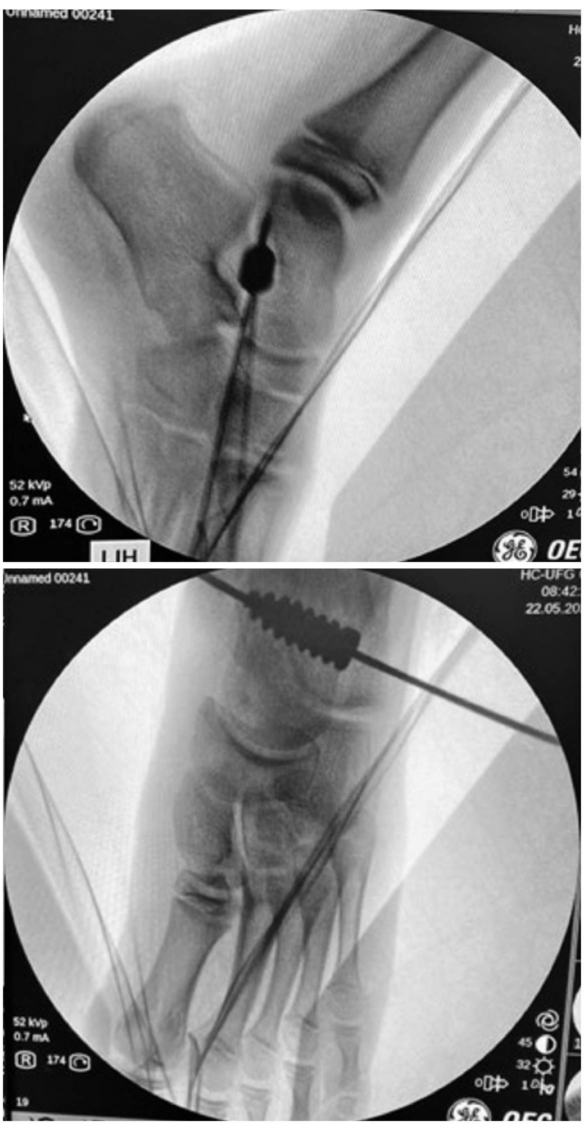

Figure 4. Intraoperative fluoroscopy.

Table 1. Profile characterization of patients in the control and intervention groups

	Groups		Total	p
	Control 6 (37.5)	Intervention 10 (62.5)		
Mean ± SD				
Age (years)	11.67 ± 0.52	12.30 ± 1.64	12.06 ± 1.34	0.38**
	n (%)			
Sex				
Female	0 (0.0)	7 (70.0)	7 (43.8)	0.07*
Male	6 (100.0)	3 (30.0)	9 (56.3)	
Foot				
Right	3 (50.0)	6 (60.0)	9 (56.3)	0.69*
Left	3 (50.0)	4 (40.0)	7 (43.8)	

*Chi-square test; **Student's *t*-test; n = absolute frequency; % = relative frequency; SD = standard deviation.

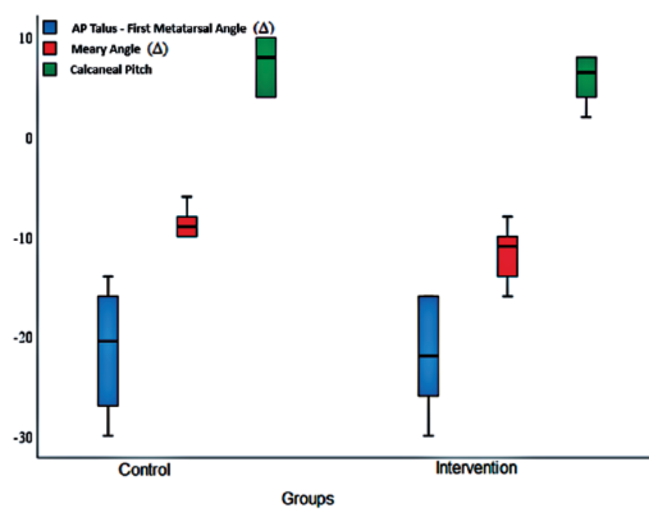

Figure 5. Boxplot graph comparing the delta values of angles between the control and intervention groups.

An improvement in the quality of life of patients was observed, as indicated by the improved SF-36 scale scores obtained. Questions regarding pain and limitation due to physical aspects were the ones that stood out positively as the greatest benefits, considering all general means in the pre-and postoperative periods. Respective scores were preoperatively, 64.5 and 66.6 points, and, postoperatively, 93 and 95 points (Figure 7).

Table 2. Angle comparison pre-and postoperatively in the control and intervention groups

Mean ± SD	Control		p*	Intervention		p*
	Preop	Postop		Preop	Postop	
AP talus-first metatarsal angle	25.33 ± 5.32	4.00 ± 2.28	0.001	25.50 ± 4.60	3.40 ± 2.17	<0.001
Meary angle	13.67 ± 0.82	5.00 ± 1.10	<0.001	16.40 ± 4.30	4.60 ± 2.67	<0.001
Calcaneal pitch angle	4.67 ± 1.03	12.00 ± 2.53	0.001	4.70 ± 1.64	10.60 ± 1.90	<0.001

*Paired *t*-test; AP = anteroposterior; Preop = preoperatively; Postop = postoperatively; SD = standard deviation.

Score	Variation
Pain	0 to 40
Function	0 to 45
Limitation of activities	0 to 10
Type of footwear	0 to 5
Maximum walking distance	0 to 10
Walking surfaces	0 to 10
Gait abnormality	0 to 10
Foot alignment	0 to 15
Total	**100%**

Figure 6. Overall mean score on the AOFAS questionnaire applied to patients evaluated preoperatively and postoperatively.
Source: Rodrigues RC, Masiero D, Mizusaki JM, Imoto AM; et al. 2008 [7]

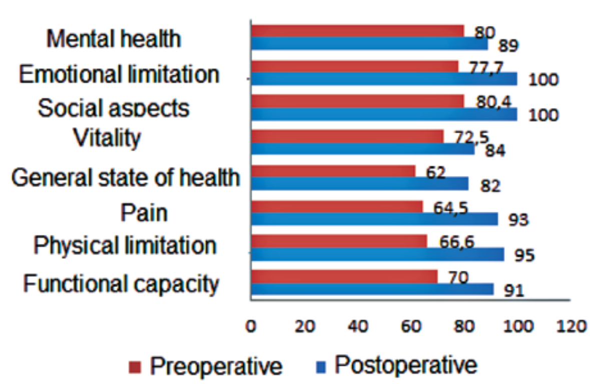

Figure 7. Overall mean score on the SF-36 questionnaire applied to patients evaluated preoperatively and postoperatively.

Figures 8 and 9 show a radiographic comparison of the pre- and postoperative posteroanterior projections of a patient.

Discussion

For Bernasconi[8], flexible flatfoot is a complex and multiplanar deformity, where pain is a constant and determining factor for surgical treatment indication. Currently, there are not enough data to explain why a flexible flatfoot remains asymptomatic or becomes painful, with the exception of cases in which the deformity is advanced and gait dysfunction is present.

Figure 8. Preoperative anteroposterior radiographs.

Figure 9. Postoperative anteroposterior radiographs.

It is a multifactorial pathology with presence of increased stresses on the ligaments that support the arch and the posterior tibial tendon. In most cases, it is associated with other risk factors, such as obesity, hypertension, diabetes, and high impact sports[9].

The true incidence of this condition is unknown, mainly because there is no consensus on the strict clinical or radiographic criteria for its definition[2]. However, it was observed in this study that the prevalence in females was higher, agreeing with literature [9].

There are several treatment options for flexible flatfoot. Although there is still no consensus on the best treatment protocol, subtalar arthroereisis deserves to be highlighted because it is a little invasive procedure that provides faster patient return to daily life activities, with less pain when compared to other surgical techniques[10-11].

According to Giannini[12], there is a variety of arthroereisis implants currently available, which can be divided into bioabsorbable, non-absorbable, or combined implants. Higher complication rates have been observed in absorbable implants. The properties of implants consist of axis change, impact locking, and self-locking. Some implants can cross several categories and differ in various sizes; all of them are capable of multiplanar correction of the deformity.

Despite such variety, the cost of implants is still very high, which becomes an obstacle to the development of the technique and access to such treatment.

The present study aimed to analyze the use of an alternative implant – the interference screw –, which demonstrated excellent postoperative results, with a significant decrease in material costs. The average price of the interference screw corresponds to 8% of the value of the standard implant used in the conventional technique. The interference screw has an average cost of US$40 according to the Brazilian Unified Health System (SUS) table, while the conventional prosthesis has an average cost of US$500.

As observed by Deland[5], treatment of subtalar arthroereisis with conventional implants was able to produce a remarkable improvement in the axes of diseased feet, as well as to increase AOFAS questionnaire scores when compared preoperatively and postoperatively. This result is similar to that found in the present study, where the pre-and postoperative quality of life measured by the SF-36 questionnaire was also assessed.

Despite the favorable results found, complication rates of subtalar arthroereisis vary from 30% to 40%, and main complications include persistent pain in the tarsal sinus, osteonecrosis, subtalar arthroereisis, overcorrection, loosening or breaking of the implant, subluxation, incorrect fixation, and fractures[10].

To perform the procedure, it is necessary to observe the technique, as well as to choose the appropriate implant size in order to reduce the possibility of complications inherent to the treatment, taking into account the need to adapt the size of the implant to its insertion point in the patient's joint, preventing it from being protruding or loose at the insertion point.

The angular results seen in radiographs and clinically observed on the AOFAS questionnaire for patients in whom interference screws were used are similar to those obtained by the conventional technique, with a mean follow-up time of 58 months for those treated with the interference screw and 32 months for those treated with the conventional technique. However, statistical analysis resulted in a high *p*-value for the AP talus-first metatarsal angle (Δ) and for the calcaneal pitch angle (Δ), as seen in Table 3. We credit this result to the small number of patients enrolled in the study.

Conclusion

In this study, we conclude that subtalar arthroereisis using interference screw is a treatment choice for patients with flexible flatfoot.

It should also be considered that the interference screw has a lower financial cost, facilitating access to the procedure and increasing medical indications.

We emphasize the importance of good anteroposterior and lateral radiographs with load to evaluate the plantar arch, subtalar space, and implant positioning, identifying possible complications.

Results of this investigation corroborate those of current scientific studies, and we believe that additional studies on the treatment of these lesions deserve to be highlighted.

Table 3. Angle delta comparison between the control and intervention groups

Mean ± SD	Groups		p*
	Control	Intervention	
AP talus-first metatarsal angle (Δ)	-21.33 ± 6.80	-22.10 ± 5.63	0.713
Meary angle (Δ)	-8.67 ± 1.63	-11.80 ± 2.57	0.031
Calcaneal pitch angle (Δ)	7.33 ± 2.73	5.90 ± 2.33	0.312

*Mann-Whitney; AP = anteroposterior; SD = standard deviation.

Authors' contributions: Each author contributed individually and significantly to the development of this article: JSM *(https://orcid.org/0000-0003-4742-1905). Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, performed the surgeries, data collection, bibliographic review, survey of the medical records, clinical examination and approved the final version; LVP *(https://orcid.org/0000-0002-4695-637X), and LOS *(https://orcid.org/0009-0001-4979-7826) Performed the surgeries, formatting of the article, interpreted the results of the study, participated in the review process, approved the final version, statistical analysis; LPSDC *(https://orcid.org/0000-0003-1477-4341), and GDFR *(https://orcid.org/0000-0003-4979-7826), and JYHF *(https://orcid.org/0000-0002-9154-2782), and IOCDM *(https://orcid.org/0000-0001-6281-1480) performed the surgeries, conceived and planned the activities that led to the study, bibliographic review. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Original Article

Fixation methods of Chevron osteotomy in percutaneous surgery for hallux valgus: a comparative study

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Abstract

Objectives: Evaluate the results of percutaneous surgery for hallux valgus, comparing three fixation methods of Chevron osteotomy of the first metatarsal.

Methods: Seventy-one feet were submitted to percutaneous surgery with Chevron osteotomy between 2017 and 2022; 41 feet were fixed with screws, 18 with two Kirschner wires, and 12 with one screw and one Kirschner wire. Clinical results were evaluated using the American Orthopaedic Foot & Ankle Society (AOFAS) Hallux Metatarsophalangeal-Interphalangeal Score (MTP-IP). Radiographic outcomes included hallux valgus angle (HAV), intermetatarsal angle (IMA), distal metatarsal articular angle (DMAA), and sesamoid displacement (SD). Patients had a mean follow-up of 25 months.

Results: No statistically significant difference was found among the three groups in the AOFAS score ($p < 0.001$). The means of HVA, IMA, DMAA, and SD decreased from preoperative to postoperative in all techniques similarly. Among the total sample, 17 presented some complications. There was no statistically significant difference in complications among the techniques.

Conclusion: Clinical and radiological results of the three fixation methods for percutaneous Chevron osteotomies were equivalent, with no disadvantage regarding radiographic parameters or increased operative complications.

Level of Evidence IV; Therapeutic Studies; Case Series.

Keywords: Hallux Valgus; Bunion; Minimally invasive surgery.

Introduction

Hallux valgus (HV) is the main forefoot pathology, where the hallux deviates laterally in valgus, also by a medial deviation of the first metatarsal head, producing a medial bone protrusion in the first metatarsophalangeal joint region[1]. It mainly affects women due to the great influence of narrow footwear and high heels[2].

Conservative treatment may produce pain relief in patients with HV, but is inefficient to correct the deformity[2]. For this reason, surgical intervention is indicated for symptomatic cases, aiming to realign the first ray, keeping the forefoot biomechanically functional[3,4].

Minimally invasive techniques are commonly chosen as surgical interventions[3]. In HV, these techniques stand out for presenting some advantages over conventional techniques, such as allowing outpatient surgeries with local anesthesia and small or punctate incisions, the non-routine use of synthesis material, the release for immediate postoperative ambulation, in addition to presenting a lower incidence of complications with the surgical wound and lower pain intensity after the procedure[4,5].

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

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The Chevron V-osteotomy, described by Austin e Leventen[6] as an open procedure for HV treatment, is a biplanar bone cut on the transverse and vertical planes with lateral displacement, maintaining stability in the vertical plane. The literature shows good results and, therefore, the most-performed technique worldwide[7]. Vernois and Redfern[8] demonstrated percutaneous osteotomy using fixation with screws in severe cases, which guarantees greater stability when the head displacement of the first metatarsal needs to be greater[9]. It is known that in some services, especially in the Unified Health System (SUS), screws are often not available, and other materials, such as Kirschner wires (K-wire), are routinely used as a substitute for fixing osteotomies. However, no studies have compared the results of Chevron osteotomy fixation using different synthesis materials.

Given the lack of evidence as mentioned above, the objective of the study is to:

- Compare the results of three fixation methods (with two screws, with two K-wires, and combined with a screw and a K-wire) in percutaneous Chevron osteotomy of the first metatarsal, based on radiographic parameters of hallux valgus angle (HAV), intermetatarsal angle (IMA), distal metatarsal articular angle (DMAA), and sesamoid displacement (SD) and clinical results using the American Orthopaedic Foot & Ankle Society (AOFAS) scale[10], in the pre-and postoperative;
- Verify the incidence of reduction in fixation among the groups;
- Correlate the incidence of complications and the different synthesis techniques.

Methods

This study was approved by the Institutional Review Board under the number 70032723.4.0000.5501.

From November 2017 to October 2022, 68 patients were selected from the database of an Orthopedics and Traumatology service, totaling 71 feet with symptomatic HV, classified as moderate to severe, submitted to percutaneous Chevron Osteotomy, fixed with cannulated screws 4.0 and 3.0 mm and/or K-wires 2.5 mm. The procedures were performed by three experienced surgeons and service fellows, always under supervision.

Among the 71 feet submitted to the intervention, 41 were fixed exclusively with screws, 18 only with K-wires, and 12 with combined fixation, using a K-wire and a screw. Follow-up ranged from six months to five years and nine months, with a mean of 25 months. The chosen fixation method determined the allocation in the groups (group S, group W, and group SW). It is important to highlight that the decision on the method was guided by the availability of materials in the service, giving preference to screws whenever they were available. Additional procedures performed simultaneously included a Tailor's bunion foot, 34 metatarsalgias, and 23 claw toes.

Patients with mild HV, rheumatoid arthritis, neuromuscular disorders, bone-degenerative changes of the hallux metatarsophalangeal joint, and previous surgeries in the first ray were excluded.

All participating patients were informed about the objectives of the study and signed the Informed Consent Form, a mandatory criterion for participation in the study.

Clinical and radiographic evaluation in all feet were performed individually and subsequently intergroup. The pre-and postoperative radiographic evaluation (in the anteroposterior and lateral profile with weight-bearing) was performed by two orthopedists (fellows), measuring the HAV, IMA, DMAA, and SD. Clinical and functional evaluation was performed according to the AOFAS scale, with responses collected by the senior orthopedist.

Descriptive analyses were performed by a statistical professional. For categorical variables, absolute and relative frequencies were presented, and for numerical variables, summary measures (means and standard deviation). The existence of associations between two categorical variables was verified using Fisher's exact test. The distributions of a categorical variable between two evaluation moments were compared using McNemar's test.

Mixed linear regression models were used to evaluate the effects of time and technique on each dependent variable (AOFAS, HAV, IMA, and DMAA). A significance level of 5% was used for all statistical tests. Analyses were performed using the statistical package SPSS 20.0 and STATA.

Surgical Technique

The surgical technique, already consolidated and published in the literature, was performed as described by Vernois and Redfern[8], and the specific fixation characteristics of each group are detailed below.

In patients in group S, two cannulated screws introduced from medial to lateral were used to stabilize the osteotomy. The proximal screw went through the two cortical of the first metatarsal before reaching the head, making a tricortical fixation. The second screw was positioned distally and parallel to the first (Figure 1).

As described above, the surgical technique for inserting the synthesis material was performed in groups W and SW. In group W, two K-wires of 2.5 mm were used (Figure 2), while in group SW, a K-wire of 2.5 mm and a screw were used, as shown in Figure 3.

Percutaneous release of the lateral soft tissues (adductor tendon of the hallux and lateral capsule) was performed in all patients to minimize the risk of recurrence.

After osteotomy and fixation of the first metatarsal and lateral release, the relevance of performing the Akin osteotomy[11] in the proximal phalanx was analyzed. In most cases (84.5), this osteotomy was performed, except in six cases where proper alignment had already been achieved.

Figure 1. Fixation with two screws: the proximal screw crosses three cortical, while the second, more distal, two cortical.

The incisions were sutured with 4.0 Nylon thread, and the compressive dressing was performed. Weight-bearing was released from the first postoperative day with a rigid sole sandal. The dressing was changed weekly during the first four weeks by the surgical team and the patient or companion for the next two weeks. The k-wires used in groups S and SW were removed six weeks after surgery.

It is important to highlight that the degree of head translation was performed according to the severity (moderate/severe), regardless of the synthesis used.

Results

Considering the information of the 71 feet analyzed, whose mean age was 54 years (ranging from 16 to 80 years), with a predominance of females (89%), the radiographic parameters in the pre-and postoperative period of each group were evaluated, considering the means of HAV, IMA, and DMAA as shown in Table 1 and Figures 4 to 6.

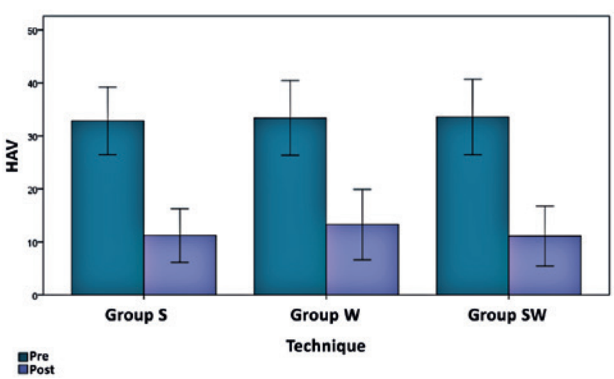
Figure 2. Fixation with K-wires: A: Preoperative radiograph; B: Preoperative clinical image; C: Fixation with K-wires; D: Radiograph with nine postoperative months, showing optimal consolidation; E: Clinical image with six postoperative weeks.

Figure 3. Fixation with K-wire and screw: A: Preoperative clinical image; B: Preoperative radiograph; C, D: Clinical image and radiograph with four postoperative weeks.

Table 1. Summary measures of AOFAS, HAV, IMA, and DMAA by technique

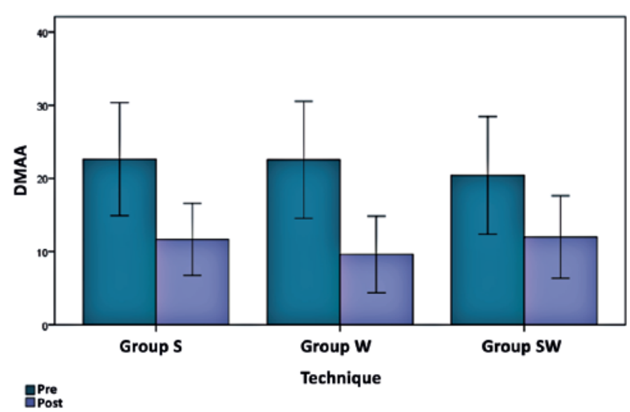
	Technique				p-value		
	Group S (N = 41; 57.7%)	Group W (N = 18; 25.4%)	Group SW (N = 12; 16.9%)	Total (N = 71; 100.0%)	Technique	Period	Technique vs. Period
AOFAS					0.468	< 0.001	0.850
Pre	38.93 ± 12.37	41.89 ± 13.79	43.00 ± 15.92	40.37 ± 13.29			
Post	89.44 ± 10.40	89.78 ± 11.43	93.33 ± 9.17	90.18 ± 10.43			
Post-Pre	50.51 ± 16.75	47.89 ± 18.44	50.33 ± 21.04	49.82 ± 17.71			
HAV					0.905	< 0.001	0.617
Pre	32.83 ± 6.38	33.39 ± 7.05	33.58 ± 7.14	33.10 ± 6.59			
Post	11.22 ± 5.08	13.28 ± 6.66	11.08 ± 5.66	11.72 ± 5.60			
Post-Pre	-21.61 ± 6.92	-20.11 ± 7.71	-22.50 ± 6.57	-21.38 ± 7.02			
IMA					0.580	< 0.001	0.307
Pre	16.34 ± 2.68	15.89 ± 2.97	15.50 ± 2.65	16.08 ± 2.73			
Post	9.90 ± 2.76	10.11 ± 2.76	7.92 ± 1.62	9.62 ± 2.69			
Post-Pre	-6.44 ± 3.12	-5.78 ± 2.96	-7.58 ± 3.92	-6.46 ± 3.23			
DMAA					0.565	< 0.001	0.300
Pre	22.63 ± 7.74	22.56 ± 7.99	20.42 ± 8.03	22.24 ± 7.78			
Post	11.66 ± 4.94	9.61 ± 5.24	12.00 ± 5.62	11.20 ± 5.14			
Post-Pre	-10.98 ± 7.67	-12.94 ± 7.72	-8.42 ± 9.51	-11.04 ± 8.03			

p: descriptive level of the mixed linear model.



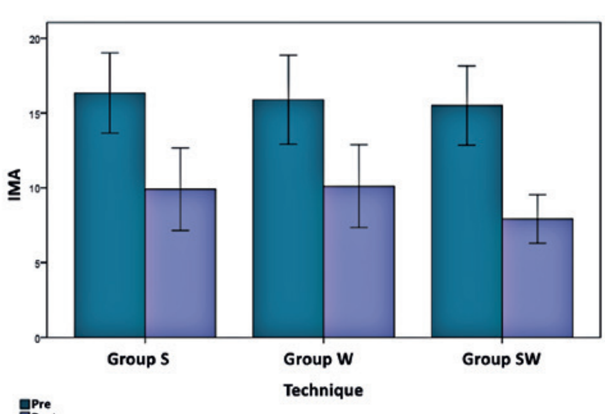
Mean ± SD
Time effect: p < 0.001, Technique effect: p = 0.905, and Technique effect on post-pre variation = 0.617.

Figure 4. HAV means by technique and period of evaluation.



Mean ± SD
Time effect: p < 0.001, Technique effect: p = 0.565, and Technique effect on post-pre variation = 0.300.

Figure 6. DMAA means by technique and period of evaluation.



Mean ± SD
Time effect: p < 0.001, Technique effect: p = 0.580, and Technique effect on post-pre variation = 0.307.

Figure 5. IMA means by technique and period of evaluation.

As for SD, there were no different distributions by technique (p = 0.598). Table 2 shows the position of the sesamoid reached in the postoperative period in the three groups regarding the displacement's improvement, maintenance, or worsening.

Regarding the clinical parameters, an increase in the AOFAS score was observed in all groups when comparing the pre- and postoperative periods, according to Table 3, without presenting a statistical difference among the techniques (Figure 7).

There was no loss of correction in either the immediate or late postoperative period and no loss of the reduction after removing the K-wire in groups S and SW. There was also no difference between the groups regarding the severity of the deformity, percentage of translation, and complications.

Table 2. Position of the sesamoid by technique in the postoperative period

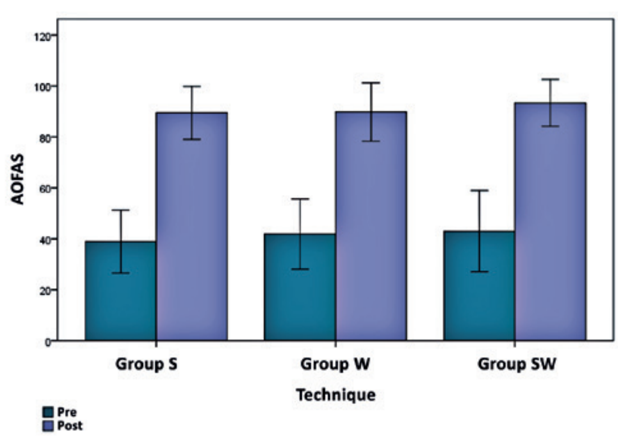
	Technique			p-value
	Group S (N = 41; 57.7%)	Group W (N = 18; 25.4%)	Group SW (N = 12; 16.9%)	
Sesamoid displacement				0.598
Improvement	34 (82.9)	14 (77.8)	11 (91.7)	
Maintenance	7 (17.1)	3 (16.7)	1 (8.3)	
Worsening	0 (0.0)	1 (5.6)	0 (0.0)	

The sum of the percentages may not total 100.0% due to rounding.
p: descriptive level of Fisher's exact test.

Table 3. Pre-and postoperative AOFAS by technique

	Mean	SD	Min	Max	Median	N
AOFAS - pre	**40.37**	**13.285**	**15**	**70**	**39**	**71**
Group S	38.93	12.372	15	65	39	41
Group W	41.89	13.792	25	69	40	18
Group SW	43	15.92	20	70	41	12
AOFAS - post	**90.18**	**10.433**	**49**	**100**	**95**	**71**
Group S	89.44	10.404	53	100	95	41
Group W	89.78	11.425	49	100	92.5	18
Group SW	93.33	9.168	72	100	97.5	12

SD: Standard deviation; Min: Minimum; Max: Maximum.



Mean ± SD
Time effect: p < 0.001, Technique effect: p = 0.468, and Technique effect on post-pre variation = 0.850.

Figure 7. AOFAS means by technique and period of evaluation.

As for complications, no different percentages per technique were found (p = 0.931). Of the total sample, 23.9% had some complications (Table 4). Complications were stratified according to the adapted classification of surgical complications for orthopedic surgery by Clavien-Dindo[12], a system that evaluates the severity of surgical complications.

In group S, the most frequent complications were related to the synthesis material, with three cases of screw migration (Figure 8) and three cases of pain in the screw head. In cases where the screw caused pain, it was removed. In addition, in this group, other complications were observed, such as fracture of the cortical bone, complex regional pain syndrome (CRPS), and a case of recurrence. In total, this group had complications of 26.8%, with classifications, according to Clavien-Dindo, ranging from 2 to 3b (Table 4).

When analyzing group W, a complication rate of 22.2% was observed, also classified from 2 to 3b. As in group S, most of these complications were associated with the synthesis material, with three early removals of one of the K-wires. Of these removals, two were due to proximal migration and one due to pain at its insertion site.

In the SW group, two complications were identified: a case of pain in the screw head, which needed to be removed, and another case of skin necrosis at the incision site, which evolved to complete resolution. These complications accounted for 16% of this group.

Discussion

The minimally invasive Chevron Akin (MICA) technique with percutaneous fixation is indicated in the surgical treatment of HV with moderate and severe deformities. The choice of this technique is due to the greater correction of HV and intermetatarsal angle. These corrections occur due to the head lateral displacement of the first metatarsal, up to 100%, associated with the fixation of this osteotomy[8]. Although some studies show different fixation methods of percutaneous Chevron osteotomy, comparing them is still a matter of discussion.

Table 4. Distribution of complications by group

	Group S (N = 41; 57.7%)	Group W (N = 18; 25.4%)	Group SW (N = 12; 16.9%)	Total	p-value
K-wire/screw removal	3 (7.31%)	1 (5.55)	1 (8.33)	5 (7.04)	**1.000**
Material migration	3 (7.31%)	1 (5.55)	0 (0.0)	4 (5.63)	**1.000**
Cortical bone fracture	2 (4.87%)	1 (5.55)	0 (0.0)	3 (4.22)	**1.000**
CRPS	1 (2.43%)	0 (0.0)	0 (0.0)	1 (1.40)	**1.000**
Skin necrosis	1 (2.43%)	0 (0.0)	1 (8.33)	2 (2.81)	**0.385**
Recurrence	1 (2.43%)	0 (0.0)	0 (0.0)	1 (1.40)	**1.000**
Hallux hypoesthesia	0 (0.0%)	1 (5.55)	0 (0.0)	1 (1.40)	**0.430**
TOTAL	**11 (26.8%)**	**4 (22.2)**	**2 (16.0)**	**17 (23.9)**	**0.931**

CRPS: complex regional pain syndrome.

Figure 8. Complications: A: Proximal screw migration; B: Result after screw removal.

The most available fixing material for performing percutaneous surgeries in the SUS is the K-wires, which have lower costs and higher and easier technical handling[13,14]. However, when screws are available, we choose them, following the classical approach of MICA technique.

Due to the variability of fixation materials, the study was divided into three groups: group S, fixed with screws; group W, fixed with K-wires; and group SW, a screw and K-wire. Due to the retrospective study design, the quantitative distribution of patients into the groups was heterogeneous. Such distribution was based on the choice of fixation material.

Our results corroborated previous findings[15,16], indicating that both K-wire and screw fixation resulted in comparable functional and radiological outcomes. In the analysis performed, the choice of implant did not affect the conduct of the surgical technique, and it was performed according to the severity and specific needs of each case.

There was no loss of correction in the immediate or late postoperative period and after removal of the K-wire. No significant disparities were identified among the groups regarding deformity severity, translation amount, and complication incidence.

Regarding the radiographic angles, there was a reduction in the means in the three techniques. The reductions were similar in the three angles analyzed, showing that all fixation methods were effective in maintaining HV correction. Better results, however, were observed in the HAV and IMA in the SW group (22.5º and 7.58º, respectively) and the DMAA in the group W (12.94º), although without statistical significance among the groups. These results indicate that the mean correction of angles was consistent with the findings of several previous studies[17-24].

As for the DMAA, the mean value obtained was 10.8°. Some studies did not evaluate the referred angle, including the studies by Carlucci et al.[25], Carvalho et al. [22], and Nunes et al. [21], with results similar to ours (8°, 8.5°, and 10.2° respectively). Regarding the sesamoids, there was a significant reduction in severe cases, changing to mild and moderate deformities in the postoperative period. This reduction was observed in the three fixation techniques, indicating their effectiveness. The study by Ferreira et al.[17] showed similar results, with good postoperative correction. However, in the literature, the evaluation of the sesamoid position was not frequently evaluated[18,19,22].

Regarding the AOFAS score, there was a significant functional improvement of the foot after surgery, with an increase in postoperative values in the three groups (mean: 40.4 to 90.2), similar to other studies[19,21,22].

In the total sample, 23.9% of patients had some complications, such as removal of material (Clavien-Dindo 3b), migration of the synthesis material (Clavien-Dindo 2), fracture of the medial cortical (Clavien-Dindo 2), CRPS (Clavien-Dindo 2), skin necrosis (Clavien-Dindo 2), recurrence of HV (Clavien-Dindo 3b), and hallux hypoesthesia (Clavien-Dindo 2) stand out (Table 4). When analyzing the groups separately, a varied distribution of complications was observed, highlighting that most were classified as Clavien-Dindo 2 and 3b in all groups, indicating complications that required observation or surgical intervention to remove the synthesis material without implying a risk of death or sequelae.

There were no significant differences among the groups. In all of them, the synthesis material was the main motivator of patient's complaints, often requiring their removal, as also evidenced in other studies[18,19,21,22,25]. Despite the eventual removal, there was no interference in the clinical and radiographic results. Another complication observed was the screw migration in 7.3% of the cases, the same reported by Carvalho et al.[22].

In a single case, the deformity recurred late, and the patient was submitted to a new surgical procedure. Hallux valgus recurrence and neuropraxia of the medial dorsal cutaneous nerve are relevant complications to be considered in minimally invasive surgeries. In our analysis and the studies by Nunes et al.[21] and Carvalho et al.[22], a low percentage of such complications was observed. Lewis et al.[18], in a recent study with a two-year follow-up, also reported a recurrence rate of 0.9%.

Armstrong et al.[26] evaluated the results of 69 patients regarding immediate postoperative morbidity, structural correction, and long-term range of motion after fixation with a single K-wire and a cortical screw. They observed that fixation with K-wire and rigid internal screws was effective, presenting good consolidation, low morbidity, and adequate stability.

It is relevant to note that the availability of fixation materials can influence the choice of technique in specific clinical contexts, as in this sample, performed in a public hospital. The significant improvement in the quality of life of patients submitted to minimally invasive surgery to correct HV justifies the continuation of these procedures to correct moderate and severe deformities.

However, we recognize that this study has limitations, including its retrospective design and the heterogeneity in the distribution of patients among the fixation groups. Therefore, future studies with larger samples, adequate randomization, and longer follow-up are needed to provide more robust evidence and guide the choice of fixation technique in the HV treatment.

In summary, based on the results of this comparative study, the three fixation techniques were effective in angular correction and displacement of the sesamoid associated with HV. Most complications were resolved in the short term and did not interfere with correction.

Conclusion

The three fixation methods effectively corrected the angular deformities associated with hallux valgus. The choice among these methods did not significantly influence the clinical and radiological results. Although material-related complications were observed, the groups had no statistically significant differences.

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Original Article

Post-traumatic hallux valgus with lateral metatarsal injuries: management and short-term results

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Abstract

Objective: Describe the epidemiology, treatment, and clinical and radiographic results of traumatic hallux valgus associated with lateral metatarsal injuries.

Methods: Clinical and radiographic evaluation (hallux valgus angle) of seven patients who suffered traffic accidents and presented post-traumatic hallux valgus associated with lateral metatarsal injuries. Radiographic measurements and clinical functional outcomes were evaluated with a minimum 12 months of follow-up.

Results: All patients were submitted to medial ligament repair to treat post-traumatic hallux valgus and fixation of the associated fractures. In a minimum 12 months of follow-up, the patients evolved well, without pain, with a mean hallux valgus angle of 13.7 degrees.

Conclusion: Cases of post-traumatic hallux valgus associated with lateral metatarsal injury, treated with ligament repair and fixation of associated fractures, showed radiographic improvement and maintained until the final evaluation after 12 months of follow-up.

Level of Evidence IV; Therapeutic Studies; Case Series.

Keywords: Posttraumatic; Hallux; Valgus; Deformity; Surgical repair.

Introduction

Hallux valgus deformity is the most common problem in the forefoot of adults[1]. Trauma is often cited as a cause, but few studies detail the characteristics of this type of hallux valgus[2-9]. Traumatic hallux valgus can be divided into two types: isolated and associated with fractures of the other metatarsal bones.

In isolated traumatic hallux valgus, only the first ray is involved. Sports trauma is primarily responsible for these injuries. The term "turf toe" was described by Bowers and Martins in 1976[10] and has since gained more attention among doctors, coaches, and athletes. There is a mechanism of hyperextension of the metatarsophalangeal joint of the hallux with an injury of the plantar plate. In cases where a valgus force component is associated with hyperextension, there is also injury to the medial collateral ligament, leading to the development of hallux valgus. Thus, isolated traumatic hallux valgus is a variant of the "turf toe," a sprain of the hallux with injury to the medial collateral ligament.

In associated traumatic hallux valgus, trauma also causes minor injuries in the lesser toes, presenting neck/head fractures of the second to fifth metatarsals. It can present as dislocations of the corresponding metatarsophalangeal joints or as fractures of the phalanges.

The etiology and epidemiology of traumatic injuries of the first metatarsophalangeal joint have been poorly documented in the literature. Only a few reports describe such injuries and the types of treatments.

Weight-bearing radiographs in frontal and lateral profiles are indicated to diagnose traumatic hallux valgus. In addition, an investigation of sesamoids should be performed with the hallux in hyperextension. When there is an injury to the medial

Study performed at the department of orthopedics and traumatology of Dr José de Carvalho Florence Hospital, São José dos Campos, São Paulo, SP, Brazil.

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collateral ligament, the tibial sesamoid tends to assume a more distal position in relation to the fibular sesamoid. Magnetic resonance imaging (MRI) may be required in cases of suspected ligament injury.

The objective of the study is to describe the epidemiology, treatment and radiographic results of traumatic hallux valgus associated with lateral metatarsal injuries treated in a tertiary hospital in the countryside of Sao Paulo state, Brazil.

Methods

A retrospective study including patients with foot trauma presenting acute post-traumatic hallux valgus and associated injuries. The study was approved by the Institutional Review Board under the number 72626123.4.0000.5451.

It was included in the study patients who suffered post-traumatic hallux valgus ("turf toe" + medial collateral ligament injury) associated with lateral metatarsal injuries submitted to surgical treatment with a minimum 12 months of follow-up. Cases of "turf toe" without ligament injury and those who lost follow-up were excluded from the study. Among the 12 patients, only seven (five men and two women) met the inclusion criteria (Table 1).

Hallux valgus angle was evaluated on preoperative radiographs and compared with the immediate postoperative and the last outpatient follow-up (minimum 12 months). Only the final radiographs were performed with weight-bearing. All measurements were performed by the two foot and ankle surgeons who conducted the service's outpatient clinic.

The clinical evaluation was performed through questionnaires on pain, return to pre-injury activities without restrictions, and degree of range of motion. The clinical evaluation was subjective and performed by the same surgeons who performed the radiographic measurements.

The majority of the associated fractures were at the neck of the second to fifth metatarsals with or without the involvement of the heads, and one of the cases had an associated fracture at the neck of the second metatarsal with a fracture at the base of the fifth metatarsal.

The surgical treatment varied according to the associated injuries. One case had an open fracture of the metatarsals with lateral dorsal degloving of the foot. The first metatarsophalangeal joint was always approached medially, and ligament repair was performed with anchors (four cases) or transosseous sutures according to the availability of materials at the time of surgery. The neck fractures of the lesser metatarsals were fixed with 1.5 mm Kirshner wires (five cases, two of which were percutaneous). Two cases also presented head fractures of the lesser metatarsals with a high degree of comminution. They were submitted to head resection by two dorsal routes on the second and fourth metatarsals.

To change the dressing, all patients had an outpatient follow-up with weekly visits in the first three weeks after surgery. In the third week, the sutures were removed. All patients were immobilized with a splint for at least six weeks. In the sixth week, the immobilization was removed, and front, lateral, and oblique radiographs were taken with no weight-bearing. Progressive weight-bearing was released from the eighth week when the Kirshner wires were removed. In the twelfth week, new radiographs were taken. The next follow-ups occur after six and 12 months. The open fracture cases required more detailed care with more frequent outpatient visits but had no complications.

Table 1. Demographic data

	Sex	Age	Trauma mechanism	Associated injuries
1	M	37	Motorcycle accident	Neck fracture from the second to fifth metatarsal (right)
2	M	33	Motorcycle accident	Neck fracture in the second metatarsal (right)
3	M	35	Motorcycle accident	Neck fracture from the second to fifth metatarsal (left)
4	F	44	Motorcycle accident	Fracture of the base of the fifth metatarsal and neck fracture of the second and third metatarsals (left)
5	M	20	Motorcycle accident	Neck fracture from the second to fifth metatarsal (left)
6	M	40	Motorcycle accident	Neck fracture from the second to fourth metatarsal (right)
7	M	24	Motorcycle accident	Neck fracture from the second to fifth metatarsal (left)

Results

Between 2018 and 2021, 12 patients with traumatic injury to the first metatarsophalangeal joint, associated with fractures of the lateral metatarsals, were admitted to the hospital's emergency room. Among these patients, seven were submitted to surgical treatment and outpatient follow-up (Figures 1, 2 and 3).

The mean age of 12 patients was 38 years and six months (range 20 to 63 years). The most frequent trauma mechanism was a motorcycle accident (seven cases). The left side was affected in four of the seven cases operated.

The mean hallux valgus angle after trauma was 24.3º. The lowest angle was 20º and the highest 32.2º; the standard deviation was 4.3.

Hallux valgus angle was also measured in the immediate postoperative radiographs. The mean angle was 10.5º, the highest angle was 18º and the lowest 2.7º; the standard deviation was 5.84º. A mean correction of 13.8º was observed in the immediate postoperative compared to the preoperative radiographs. Twelve months after surgery, the measurement ranged from 2.7º to 20.1º, with a mean of 12.5º. In the twelve-month evaluation, a mean loss of 2.1º of correction was observed but not statistically significant ($p < 0.05$) (Table 2).

Five of the seven patients are completely asymptomatic and have resumed their activities without further restrictions. Two patients complaint of residual edema and metatarsophalangeal stiffness of the hallux and the lesser toes.

Figure 1. Case 6 – preoperative radiograph. Patient with previous amputation of the middle and distal phalanx of the fourth toe not related to the trauma studied.

Figure 3. Case 6 – 12 months postoperative radiograph.

Figure 2. Case 6 – immediate postoperative radiograph.

Table 2. Measurements of hallux valgus angle

	Hallux valgus angle		
	Preoperative	Immediate postoperative	12 months postoperative
1	21.7°	15.0°	20.1°
2	25.7°	2.7°	2.7°
3	20.0°	8.0°	9.0°
4	20.0°	18.0°	18.0°
5	25.0°	15.0°	15.0°
6	25.3°	10.8°	18.7°
7	32.2°	4.1°	4.1°

Discussion

Post-traumatic hallux valgus is an uncommon condition with few reports in the literature(8). It usually develops progressively after a sprain of the hallux ("turf toe") associated with injury to the medial collateral ligament(7). Descriptions of post-traumatic hallux valgus associated with fracture of the lateral metatarsals are scarce; only a few case reports were found in the literature(2,5). We reported a case series including seven patients who presented with deformity of the first metatarsal on the initial radiographs, all associated with lateral metatarsal injuries (head or neck fractures).

Bohay et al. in 1996[5] described a case series of post-traumatic hallux valgus associated with Lisfranc dislocation fracture, and the deformity developed progressively. All cases in our study had the valgus deformity already in the acute phase, and none had an injury in the Lisfranc joint (Figure 4).

In most of the descriptions in the literature, post-traumatic hallux valgus is related to sports trauma[3,6,7,9,10]. Our cases were more severe injuries, with trauma to the entire forefoot caused by motorcycle or car accidents.

Lui, in 2013[8], described a case of acute post-traumatic hallux valgus in a 45-year-old patient with a history of car accident associated with head dislocation from the second to fifth metatarsals. The author chose to fix only the lateral metatarsals, reported a spontaneous reduction in hallux valgus, and suggested avoiding unnecessary manipulation of the first metatarsal when possible. In our series, the first metatarsal was always addressed, with medial ligament repair with anchors or transosseous sutures. Only two evolved with metatarsophalangeal stiffness in the postoperative follow-up. We believe that this ligament repair was responsible for maintaining the correction in the follow-up of our patients, and we suggest performing the repair whenever possible.

Figure 4. Case 1 – preoperative radiograph.

There was great head comminution of the lesser metatarsals in two of our patients, and we opted for acute head resection. These patients had a similar evolution to the other cases. We did not find descriptions of head resection of the lesser metatarsals in the literature, but the few reports of traumatic hallux valgus with associated injuries addressed the injuries with reduction and fixation[8].

The scarce descriptions in the literature present case series but do not evaluate any radiographic evolution of hallux valgus. The angle was measured in the preoperative, immediate postoperative, and 12 months of follow-up.

The study has limitations, such as the small sample, which was evaluated retrospectively. Also, the ligament repair was not always performed in the same manner, and the criterion was the availability of materials. Our clinical evaluation was subjective, and no functional clinical evaluation scale was applied; therefore, we could not conclude that there was clinical improvement. In addition, the outpatient evaluation was performed only by one surgeon, which was different from the measurements performed by two surgeons. Another important limitation is that the preoperative and immediate postoperative were performed without weight-bearing. It was emphasized that the comparison of measurements involved radiographs with and without weight-bearing, which can generate a bias in the final results. On the other hand, we believe that our case series of acute post-traumatic hallux valgus associated with lateral metatarsal injuries is the only one presenting radiographic evaluations with a minimum 12 months of follow-up. More cases and a longer follow-up time using functional clinical scales are necessary to assess the need for ligament repair in cases of post-traumatic hallux valgus associated with lateral metatarsal injuries.

Conclusion

Cases of post-traumatic hallux valgus associated with lateral metatarsal injury, treated with ligament repair and fixation of associated fractures, showed radiographic improvement and maintained until the final evaluation after 12 months of follow-up.

Authors' contributions: Each author contributed individually and significantly to the development of this article: MHS *(https://orcid.org/0000-0001-7969-0515), and JMPB *(https://orcid.org/0000-0002-5280-1673) conceived and planned the activities that led to the study, performed the surgeries, interpreted the results of the study, participated in the review process, bibliographic review, clinical examination, approved the final version; LNSP *(https://orcid.org/0000-000-3711-0695) data collection, statistical analysis, formatting of the article; EPP *(https://orcid.org/0000-0008-0677-5188), and MHM *(https://orcid.org/0009-0009-4927-3097), and FQT *(https://orcid.org/0009-0007-7182-5965). formatting of the article, data collection, 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

Treatment of ankle fractures with fibular nail: clinical and imaging evaluation

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Abstract

Objective: Perform a clinical and imaging evaluation of patients with ankle fractures submitted to osteosynthesis with locked nails.

Methods: Twenty-five patients submitted to surgery using the locked intramedullary nailing technique were selected between April 2018 and December 2022. Patients were over 55 years of age, with an increased risk for healing complications. The American Orthopaedic Foot & Ankle Society (AOFAS) score and visual analog pain (VAS) scale were used for clinical evaluation. The imaging parameters used were the talocrural angle, the medial clear space, and the tibiofibular anterior line.

Results: The AOFAS score was evaluated with a mean of 83.48 (± 15.34), a minimum of 40, and a maximum of 98 points. The mean in the VAS scale was 2.56 points (± 2.50), with a minimum of 0 and a maximum of 8. The difference between the mean and the reference value (2 mm) was 0.38 mm in the tibiofibular anterior line. Regarding the medial clear space, 100% presented values within the reference (up to 4 mm). In the talocrural angle, the mean was 80.19 (± 2.93), with a minimum of 73.5 and a maximum of 86.29, within normal values.

Conclusion: Osteosynthesis of ankle fractures using locked intramedullary nails seems to be an alternative for older patients at increased risk. Despite not showing a satisfactory reduction in syndesmosis reduction, in most cases, the method showed good functional results in medium-term follow-ups.

Level of Evidence II; Therapeutic Studies; Prospectived comparative study.

Keywords: Ankle fractures; Fracture fixation, intramedullary; Elderly; Ankle Joint; Fracture healing.

Introduction

Ankle fractures are very frequent injuries, with an incidence of 184 per 100,000 people per year, with 20 to 30% of cases occurring in older people and showing an incidence with progressive increase in this population[1,2]. In this group of patients, osteoporosis and comorbidities such as diabetes, dementia, and renal failure may represent challenges to treatment[3]. Local and systemic complications are more common in this group, and medical professionals should be vigilant to avoid them.

The classic treatment of ankle fractures is performed by open reduction and internal fixation with lateral malleolus plate and screws. This procedure often requires greater tissue dissection with a potential risk of soft tissue devitalization. With relative frequency, there are complications such as difficulty in healing, skin necrosis, and even implant exposure[3].

Techniques with less tissue invasion and aggression were developed to mitigate such complications, which reduce hospitalization time and promote early rehabilitation[4,5].

Fibula intramedullary fixation techniques were created more than 30 years ago and have undergone development and improvement in the last two decades[6]. Currently, there are already locked nails available that allow the insertion of screws to close the tibiofibular syndesmosis[6]. The starting point of treatment with the intramedullary nail is a non-

Study performed at the Hospital Francisco José Neves - Unimed BH, Minas Gerais, MG, Brazil.

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anatomical reduction of the fracture but respecting the soft tissues with little interference with the biology of fracture consolidation. Another advantage is that it does not cause skin prominence or require a second removal procedure.

Adequate fracture reduction is indispensable to prevent joint congruence and post-traumatic arthrosis[7]. Studies comparing intramedullary nails with locking plates show lower complication rates and greater resistance to nail failure, encouraging using this material in unstable ankle fractures[8,9]. In addition, a systematic review comparing functional results showed similar results between the two groups after 12 months[10]. However, few studies show long-term follow-up and postoperative radiographic/tomographic evaluation.

The objective of this study is to perform a postoperative clinical evaluation with a radiographic and tomographic correlation of ankle fracture reduction after osteosynthesis with locked nails, analyzing the fibula length, tibiotalar reduction, and syndesmosis through parameters already defined in the literature.

Methods

This is a retrospective study approved by the Institutional Review Board under the number 3.739.529. All patients signed an informed consent form. The study included patients submitted to surgery due to unstable ankle fractures, classified as Weber types B and C, using locked intramedullary nails-a minimally invasive technique. The surgeries were performed between April 2018 and December 2022 by the foot and ankle surgery team at Hospital Francisco José Neves. The inclusion criteria were patients over 55 years of age with increased risk for healing complications and infection (patients with diabetes, smokers, adverse soft tissue conditions, or very old age). All patients were submitted to postoperative radiographs and computed tomography. Among the 53 patients submitted to surgery during the period, five died, and 25 met the inclusion criteria and participated in the imaging analysis. Of these 25 patients, 21 were female and four male, with a mean age of 74.04 years (± 10.46), ranging from 57 to 92 years. The mean follow-up time was 37.16 months (± 16.5), ranging from 6 to 58 months. The mean time of the surgical procedure was 4.56 days (0 to 30 days) from the date of the fracture.

Regarding comorbidities, 92% of patients had some clinical comorbidities under treatment; 21 patients were hypertensive, ten had diabetes, three had chronic obstructive pulmonary disease, and two had heart disease. In addition, five patients were chronic smokers.

Among the 25 patients, ten fractured the right side and 15 the left. Regarding the type of fracture, five had an isolated fracture of the lateral malleolus with a complete injury of the deltoid ligament, nine had a bimalleolar fracture, and 11 patients had a trimalleolar fracture. Among the 20 patients with bi-or trimalleolar fractures, ten had the fixation of the medial malleolus using one cannulated screw, seven by percutaneous technique, and three by open technique; in five cases, the medial malleolus was fixed with two cannulated screws and another five patients by medial sutures. Of the 11 patients with posterior malleolus fracture, only three required fixations, performed by a cannulated screw passed through the percutaneous posterolateral.

Patients with less than six months after surgery, under 55 years, with a fibular canal smaller than 3.0 mm in diameter, and patients who did not adequately perform imaging control were excluded from the study.

Surgical technique

Three foot and ankle surgeons (RAG, AHG, and JMBM) performed the surgery following the same principles and positioning[11]. Patients were submitted to spinal anesthetic block and cardiovascular monitoring, positioned in dorsal decubitus with a pad under the hip on the fractured side to maintain the limb at 30º internal rotation (Figure 1). The operated limbs were subjected to asepsis with a chlorhexidine solution and later with an alcohol-based solution.

In all cases of bi-or trimalleolar fractures, except for one patient, the lateral malleolus was addressed first. The initiative to start with the medial malleolus was motivated by the comminution of the fibula in this case and the subsequent loss of height reference during reduction.

The surgical technique was performed following the steps below:

1. Small longitudinal inframalleolar incision of 1.0 cm;
2. Introduction of guide through the lower end of the fibula under fluoroscopic; view (Figure 2);
3. Drilling of distal fragment channel up to 7.0 mm;
4. Drilling of proximal fragment up to 4.0 mm;
5. Introduction and passage of the locked nail (Hexagon Ind. E Com. Ltda®, Itapira/SP, Brazil) after an internal rotation maneuver of the foot, eventually using a percutaneous reducing clamp (Figure 3);

Figure 1. Patients position on the operating table.

6. Distal locking with two screws;
7. Open or percutaneous medial fixation with one or two cannulated screws (Hexagon Ind. E Com. Ltda®, Itapira/SP, Brazil) or sutures with Aciflex 5.0 (Ethicon, Johnson and Johnson do Brasil®);
8. Syndesmosis fixation through the nail with one or two screws;
9. Fixation of the posterior malleolus when necessary through the percutaneous posterolateral.

Postoperative period

Patients were followed up in outpatient consultations one, two, three, six, and twelve weeks after the surgical procedure and later at six and twelve months.

After a minimum follow-up of six months, all patients were submitted to radiographs and computed tomography to confirm fracture consolidation and evaluate the reduction.

The radiographs were performed in anteroposterior, anteroposterior views with 15º internal and lateral rotation without weight-bearing. In the anteroposterior view, with 15º internal rotation, the talocrural angle and medial clear space were marked and measured to verify the possibility of fibular shortening.

The tomographic evaluation (Alexion Advance, Canon®) was performed to confirm the fracture consolidation and evaluate the other parameters of joint reduction. In the axial evaluation at 10 mm proximal to the ankle articular line, the parameter of the tibiofibular line was measured, and the distance between the anterolateral surface of the fibula and

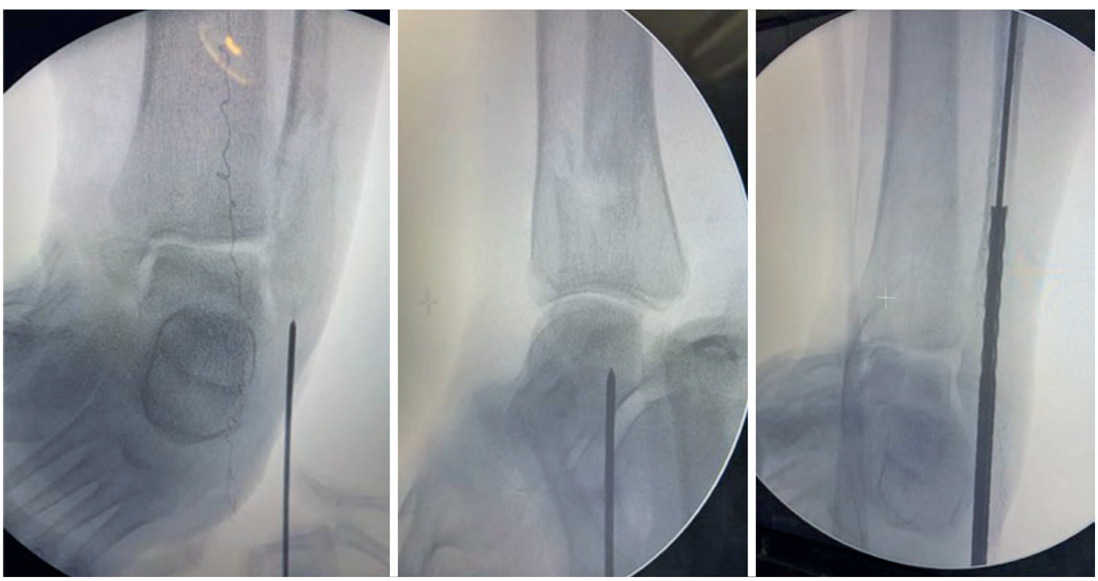

Figure 2. Guide introduction under fluoroscopic view and milling of the spinal canal.

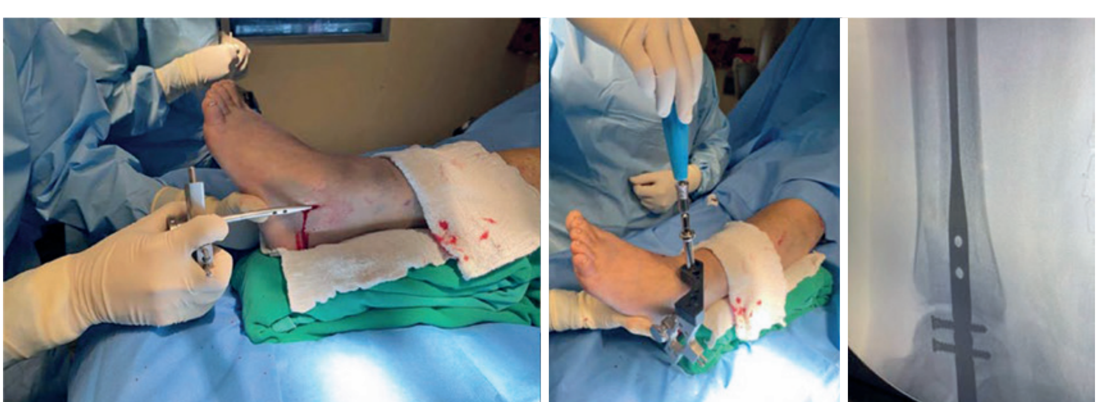

Figure 3. Nail introduction and distal locking.

the anterolateral border of the tibia[10] was recorded (Figure 4). These parameters were used to evaluate the tibiofibular syndesmosis reduction and tibiotarsal joint congruence and performed only on the operated side. The results were compared with the reference values described in the literature.

The patients were evaluated after a minimum follow-up of six months (mean of 37.1 months) and submitted to analysis using the American Orthopaedic Foot & Ankle Society (AOFAS) score[12] and visual analog pain (VAS) scale[13].

Statistical analysis

An exploratory analysis was performed using the Shapiro-Wilk test to determine the data normality with continuous distribution. Considering the parametric nature of the data, measures of central tendency (mean and standard deviation), minimum and maximum values, and the 95% confidence interval (95% CI) of each variable were obtained.

The Bland-Altman plot was used to evaluate the agreement between the values obtained in the radiographic and tomographic evaluation (tibiofibular anterior line, medial clear space, and talocrural angle) regarding the reference values of each parameter. This graph allows a visual analysis of the overall agreement and the identification of possible discrepancies between the two measures. Statistical analysis was performed using Microsoft Excel® and STATA® software (version 14.0, Stata Corporation, College Station, TX, USA).

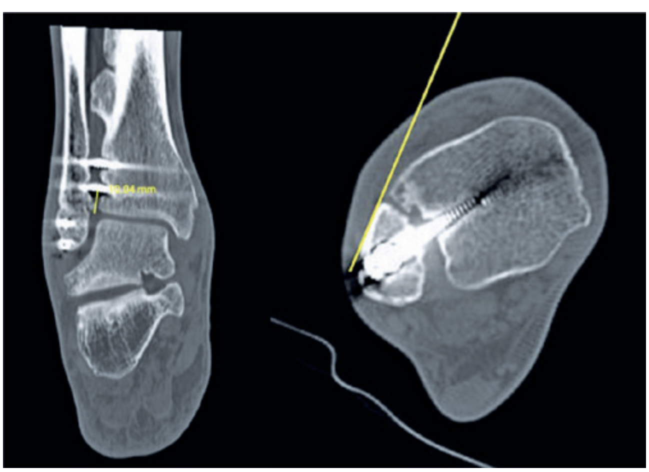

Figure 4. Axial tomographic section showing tibiofibular line marking.

Results

Considering the AOFAS score (Table 1), the patients analyzed had a mean of 83.48 points (± 15.34), with a minimum of 40 and a maximum of 98 points. On the VAS, the mean was 2.56 points (± 2.50), with a minimum of 0 (no pain) and a maximum of 8 (severe pain). To categorize the pain using this instrument, 60.00% of patients (15/25) presented mild pain (score from 0 to 2), 36.00% (9/25) moderate pain (score from 3 to 7) and only 4.00% (1/25) severe pain (score = 8).

The results comparing the values obtained in the three parameters of the tomographic evaluation vs. the reference values of each of the parameters are shown in table 2. In the tibiofibular anterior line, the difference between the mean and the reference value (2 mm) was 0.38 mm. When analyzing the individual values, it was observed that 48.00% of patients (12/25) presented values within the reference limit (2 mm), 28% (7/25) presented values between 2 mm and 4 mm, while 24.00% (6/25) presented values above 4 mm.

Regarding the medial clear space, 100% of the sample presented values within the reference limit (4 mm). In the analysis of the talocrural angle, the mean of the differences obtained between the values of each patient and the reference also suggests compliance with the reference limit (83° ± 4). However, in the individual analyses, it was observed that 28.00% of patients (7/25) presented values below 79°, outside the limit established in the literature (Table 2).

The Bland-Altman plot was used to identify the possible discrepancies between the values obtained in the radiographic and tomographic evaluation (tibiofibular anterior line, medial clear space, and talocrural angle) regarding the reference values of each parameter. Figure 5 shows the concordance analysis of the differences between the values presented in the tibiofibular anterior line and the reference value. The difference between these two measurements was 0.38 mm (continuous line), with limits of concordance (95%) of 3.76 and 4.53 mm (lower and upper dashed lines). According to these results, most points are concentrated

Table 1. Descriptive analysis of age, tomographic evaluation, and AOFAS and VAS scores

Patients (n = 25)	Mean	± SD	Min	Max	95%CI	
Age (years)	74.04	10.46	57	92	69.72	78.36
Follow-up (months)	37.16	16.50	6	58	30.35	43.97
Tibiofibular anterior line (mm)	2.38	2.12	0	8.22	1.51	3.26
Medial clear space (mm)	2.55	0.72	1.41	3.98	2.25	2.85
Talocrural angle (º)	80.19	2.93	73.5	86.29	78.98	81.39
AOFAS	83.48	15.34	40	98	77.15	89.81
VAS	2.56	2.50	0	8	1.53	3.59

SD: Standard deviation; Min: Minimum value; Max: Maximum value; 95%CI: 95% confidence interval; AOFAS: American Society of Foot and Ankle Surgery; VAS: Visual Analogue Pain Scale.

within the normal limits, indicating a good concordance between the measures. However, one point was above this limit, suggesting a specific case of disagreement (difference between the values of 6.22 mm).

Figure 6 shows the concordance analysis of the differences between the values presented in the medial clear space and the reference value, All patients were concentrated within the normal limits, indicating good concordance between the measures. The difference between these two variables was -1.45 mm (continuous line), with limits of concordance (95%) of -2.86 and -0.05 mm (lower and upper dashed lines) (Figure 6).

Figure 7 shows the concordance analysis of the differences between the talocrural angle and the reference value. The difference between these two measurements was -0.62 mm (continuous line), with limits of concordance (95%) of -3.20 and 1.95 mm (lower and upper dashed lines). According to these results, most points are concentrated within the normal

Table 2. Comparison between the mean obtained in the tomographic evaluation and the reference values

	Reference value	Means (± SD)	Difference between means and reference value
Tibiofibular anterior line (mm)			
	Up to 2 mm	2.38 mm (± 2.12)	0.38 mm
		n	**%**
	Up to 2 mm	12	48.00
	2 mm to 4 mm	7	28.00
	> 4 mm	6	24.00
	Total	**25**	**100.00**
Medial clear space (mm)			
	Up tp 4 mm	2.55 mm (± 0.72)	-1.45 mm
		n	**%**
	Até 4 mm	25	100.00
	Total	**25**	**100.00**
Talocrural angle (º)			
	83º (± 4)	80.19º (± 2.93)	-0.62º
		n	**%**
	79º to 87º	18	72.00
	< 79º	7	28.00
	Total	**25**	**100.00**

n: Absolute frequency.

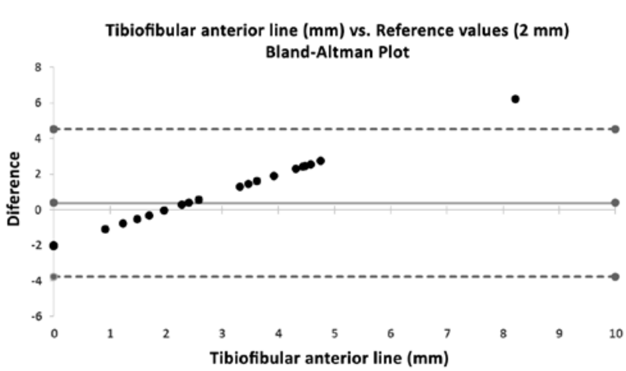

Figure 5. Bland-Altman plot (n = 25): concordance analysis between the values presented in the tibiofibular anterior line and the reference value. The bias was 0.38 ± 2.12 mm (continuous line). The limits of concordance (95%) were 3.76 and 4.53 mm (lower and upper dashed lines).

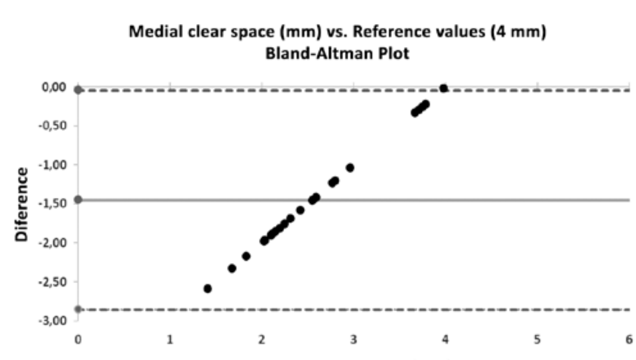

Figure 6. Bland-Altman plot (n = 25): concordance analysis between the values presented in the medial clear space and the reference value. The bias was -1.45 ± 0.72 mm (continuous line). The limits of concordance (95%) were -2.86 and -0.05 mm (lower and upper dashed lines).

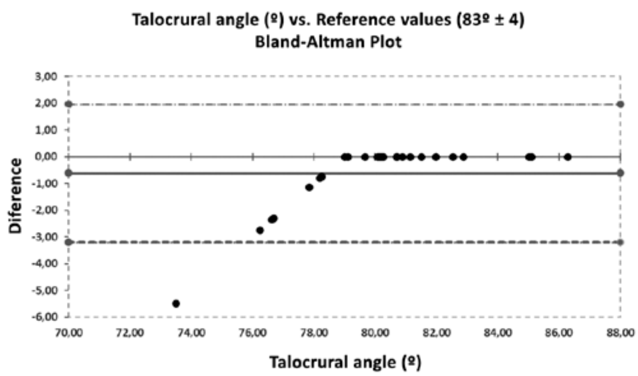

Figure 7. Bland-Altman plot (n = 25): concordance analysis between the values presented in the talocrural angle and the reference value. The bias was -0.62 ± 1.31 mm (continuous line). The limits of agreement (95%) were -3.20 and 1.95 mm (lower and upper dashed lines).

limits, indicating good concordance between the measures. However, one point fell below this limit, suggesting a specific case of disagreement (difference between the values of -5.50 mm).

In postoperative outpatient evaluation, six complications (24%) were observed: two superficial infections (8%), two medial wound dehiscence (8%), one deep infection (4%), and venous thrombosis event (4%) after one month. Patients with superficial infection were treated with oral antibiotics, and cases of wound dehiscence and deep infection were submitted to surgical debridement and use of intravenous antibiotic therapy.

Discussion

Our results indicated that the surgical treatment of ankle fractures with fixation of the lateral malleolus using a locked intramedullary nail showed satisfactory functionality and reduced the incidence of complications. Regarding the imaging parameters, the medial clear space and the talocrural angle were within the reference limits in most patients. However, the tibiofibular anterior line showed a greater variation in less than half of the cases but within the reference values proposed by Gifford et al.[10]. Based on these findings, after intramedullary fixation, syndesmosis reduction was observed, not totally satisfactory in most patients, leading to the hypothesis that this may not be reflected in a worse functional outcome in the studied population. These findings align with previous results in the literature, which demonstrated that the surgical treatment of ankle fractures through an intramedullary nail results in satisfactory functionality[14].

Our study evaluated the syndesmosis reduction through the tibiofibular anterior line in the axial section of computed tomography, which correlates with an appropriate syndesmosis reduction[10]. This parameter is relevant since an inadequate reduction can trigger complications, including premature arthrosis, with worse clinical outcomes[15]. In addition, it is known that nail treatment, due to its lower aggressiveness compared to open reduction and internal fixation with plate and screws, is associated with a lower incidence of skin complications[14,16], with surgical wound dehiscence being the main complication, occurring more frequently in diabetic patients[17].

The same favorable functionality results are observed when evaluating young patients. However, due to the lower incidence of wound complications, this population did not obtain a significant benefit compared to the treatment with open reduction and internal fixation[18]. In addition, a biomechanical investigation demonstrated nail superiority in relation to plate fixation when exposed to rotational stress, presenting greater failure torque in the first method, thus corroborating the stability of this type of construct for unstable fractures[5]. Thus, the modest correlation between imaging parameters, suggesting an inadequate syndesmosis reduction in most patients, and the good functional outcome is related to the nail treatment may be associated with a stable fixation and consolidation rate comparable to traditional plate treatment[5].

A limitation of this study was the short follow-up period, which may have been insufficient to assess long-term complications such as the development of post-traumatic arthrosis. Another relevant limitation concerns the diverse pattern of fractures and fixation techniques of the medial malleolus, with no comparison being made among the results of unimalleolar and bi- and trimalleolar fractures.

It is important to highlight that the analyzed population had a mean age of 74.04 years, within the age group that is often associated with comorbidities resulting in hospitalizations for reasons other than fractures, compromising the follow-up. Additionally, the study period was the same as the coronavirus pandemic and post-pandemic, during which many individuals avoided leaving their homes, potentially affecting re-evaluations. Due to these challenges, it was difficult to collect data and evaluate some patients, impacting the sample size. The results presented are clinically relevant because, as well as previous publications, they support using nails in populations at high risk of postoperative complications, especially wound dehiscence.

It is important to emphasize that the retrospective design, the absence of a control group or comparison with other osteosynthesis methods, and the absence of randomization in the treatment selection are also limitations. Future studies could compare imaging outcomes between nail and plate fixation, providing a deeper understanding of the relationship between reduction quality and the treatment method adopted.

Conclusion

Osteosynthesis of ankle fractures using locked intramedullary nails seems to be an alternative for older patients at increased risk. Despite not showing a satisfactory reduction in syndesmosis reduction, in most cases, the method showed good functional results in medium-term follow-ups.

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Original Article

Translation of AOFAS Hallux Metatarsophalangeal-Interphalangeal Scale into Portuguese

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Abstract

Objective: Translate, culturally adapt, and evaluate the reproducibility of the American Orthopaedic Foot And Ankle Society (AOFAS) Hallux Metatarsophalangeal-Interphalangeal Scale questionnaire into Portuguese.

Methods: The AOFAS and the 36-Item Short Form (SF-36) questionnaires were applied to 50 patients with hallux pathologies. The methodology followed the criteria defined by Reichenheim & Moraes for translation and cultural adaptation of questionnaires.

Results: The Cronbach's alpha coefficient of the domains was 0.99, indicating excellent reliability. Scores for the first and second evaluations were 65.5 and 64.2, respectively, with high interobserver concordance (65.5 vs. 65.3). Cronbach's alpha consistency analysis and Spearman's correlation analysis were 1.0, an extremely high index.

Conclusion: According to the established criteria, the questionnaire's translation and cultural adaptation were conducted effectively, with very high interobserver concordance, and can be safely reproduced in Portuguese.

Level of evidence IV, case series.

Keywords: Hallux; AOFAS; Translation; Validation.

Introduction

Surgeries involving the foot and ankle are frequent in orthopedic practice; however, the evaluation of results in scientific studies may be questionable due to the different methods used by the researchers to evaluate them[1]. To solve this issue, a standardized instrument is necessary to compare the results of treatments with patients with the same condition[2].

It is known that the quality of life of patients with foot and ankle disorders is directly influenced by orthopedic treatments[3], therefore, the evaluation of these results with a reliable and quality methods allows comparisons between clinical trials.

As different factors influence foot injuries during recovery, monitoring the progress of each patient is essential. There is a wide variety of instruments, with items directed to the performance of daily activities, which helps the physician to understand how each individual responds to treatment. However, most of the questionnaires are available in English and are produced and applied according to the demographic and cultural characteristics of the region of origin[4-6]. Social, cultural, and linguistic differences may represent a barrier to interpreting these instruments[7].

Based on the original questionnaires, studies and validations of the established characteristics are subsequently performed[8,9].

The American Orthopaedic Foot And Ankle Society (AOFAS) questionnaire (Figure 1), produced by Kitaoka et al., is an instrument used to evaluate results in foot surgeries based on patient's complaints. It evaluates three domains: pain,

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function, and alignment, totaling 100 points, with 100 being the best clinical outcome and zero the worst[10]. Although it is a questionnaire used by most scientific studies for foot and ankle pathologies worldwide, it only has translation and cultural validation into Portuguese for the ankle and hindfoot.

The objective of this study is to translate, culturally adapt, and evaluate the reproducibility of the AOFAS Hallux Metatarsophalangeal-Interphalangeal Scale questionnaire into Portuguese, according to the protocols recommended for this type of study.

Methods

Questionnaire

The AOFAS Hallux Metatarsophalangeal-Interphalangeal Scale was used in this study, which consists of nine topics addressing three domains: pain (40 points), function (50 points), and alignment (10 points). The evaluation was performed by the examiners, using an interview and a physical examination, with a score of 100 points for the best clinical result and zero points for the worst. The result could be classified as excellent (100-90 points), good (75-89 points), fair (60-74 points), and poor (< 60 points).

Pain (40 points)	
None	40
Mild, occasional	30
Moderate, daily	20
Severe, almost always present	0
Function (45 points)	
Activity limitations	
No limitations	10
No limitations of daily activities such as employment	7
Limited daily and recreational activities	4
Severe limitation of daily and recreational activities	0
Footwear requirements	
Fashionable, conventional shoes, no insert required	5
Comfort footwear, shoe insert	3
Modified shoes or brace	0
MTP joint motion (dorsiflexion plus plantarflexion)	
Normal or mild restriction (75° or more)	10
Moderate restriction (30°–74°)	5
Severe restriction (less than 30°)	0
IP joint motion (plantarflexion)	
No restriction	5
Severe restriction (<10°)	0
MTP-IP stability (all direstions)	
Stable	5
Definitely unstable or able to disiocate	0
Callus related to hallux MTP-IP	
No callus or asymptomatic callus	5
Callus, symptomatic	0
Alignment (15 points)	
Good, hallux well aligned	15
Fair, some degree of hallux malalignment observed, no symptoms	8
Poor, obvious symptomatic malalignment	0
Total	100

AOFAS = American Orthopaedic Foot and Ankle Society.
Grading: Excellent = 90–100 points; Good = 75–89 points; Fair = 60–74 points; Poor = <60 points.

Figure 1. AOFAS questionnaire.

The translation was conducted by two independent translators and evaluated according to the criteria defined by the recommendations proposed by Reichenheim & Moraes.

First, the questionnaire to be translated was identified. Then, two independent Brazilian translators were hired, aware of the objectives of the study, aiming at a conceptual and not only literal translation of the instrument. After, two independent American translators were hired, but they were not informed about the objectives of the study to perform the back-translation to verify if the Brazilian version could be considered adequate to the standards used in the original version.

The final version was prepared by a committee composed of four foot and ankle specialists, two physiotherapists, and an independent translator to verify a patient's understanding of the questions and answers to validate the processes of translation, cultural adaptation, and application of the questionnaire among Brazilian patients (Table 1).

Table 1. Final questionnaire.

Final version
Pain (40 points)
None – 40
Mild, occasional – 30
Moderate, daily – 20
Severe, almost always present – 0
Function (45 points)
Activities limitation
No limitations – 10
No limitation of daily activities, such as those performed at work, limitation of recreational activities – 7
Limitation of daily and recreational activities – 4
Severe limitation of daily and recreational activities – 0
Footwear requirements
Fashionable, conventional footwear, no insole required – 5
Comfortable footwear, with insole – 3
Adapted footwear or brace – 0
MTP joint motion (dorsiflexion and plantarflexion)
Normal or mild restriction (75° or more) – 10
Moderate restriction (30º - 74º) – 5
Severe restriction (less than 30°) – 0
IP joint motion (plantarflexion)
No restricted – 5
Severe restriction (less than 10°) – 0
MTP-IP stability (all directions)
Stable – 5
Definitely unstable or able to disiocate – 0
Callus related to hallux MTP-IP
No callus or asymptomatic callus – 5
Callus, symptomatic – 0
Alignment (15 points)
Good, hallux well aligned – 15
Fair, some degree of hallux malalignment, asymptomatic – 8
Poor, obvious symptomatic malalignment – 0
Total: 100 points
Excellent: 90-100 points; Good: 75-89 points; Fair: 60-74 points; Poor: < 60 points.

The study's methodological design can be seen in Figure 2.

The 36-Item Short Form (SF-36) (Quality of Life) questionnaire was used to obtain a correlation and measurement, which addresses eight categories based on physical and emotional characteristics. This questionnaire consists of 36 items that evaluate functional capacity, physical aspects, pain, general health, vitality, social, emotional, and mental health. Other researchers have already translated and validated it into Portuguese[11].

Study population

After approval by the Institutional Review Board, 50 Brazilian patients were evaluated in the orthopedics and traumatology department of a tertiary hospital between 2019 and 2021. All patients signed the informed consent form.

Inclusion criteria were patients over 18 years old, with outpatient follow-up and clinical pathology diagnosis that affects the hallux with confirmation by imaging exam (Figure 3). The exclusion criteria were acute trauma, currently using immobilization cast or cognitive disorders that prevent the application of the questionnaire, or those who did not accept to sign the informed consent form.

Among the patients selected, there were no exclusions or follow-up loss in the reapplication of the questionnaires.

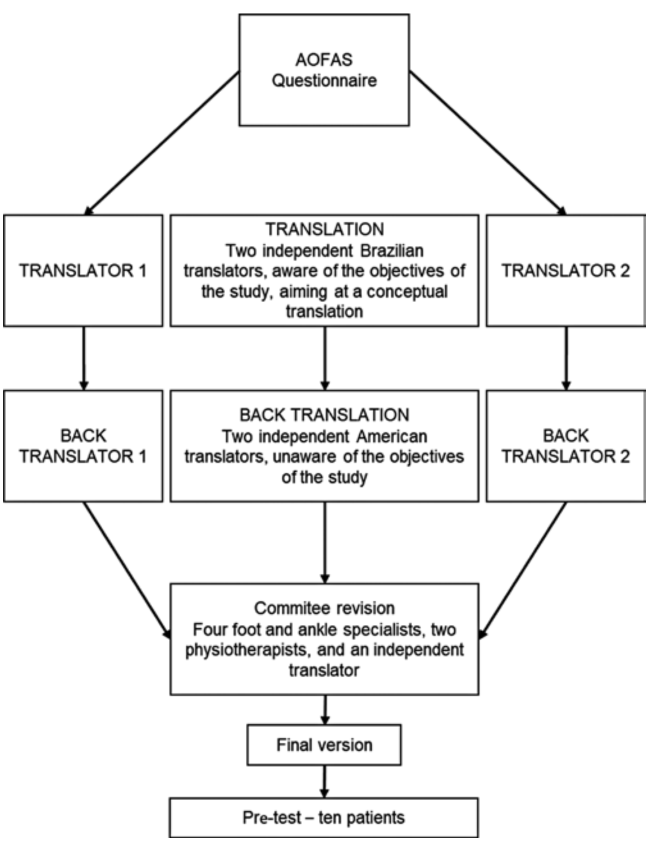

Figure 2. Methodological design.

Assessment of psychometric properties

Data were entered into Microsoft Excel software and submitted to statistical analysis through specific software to obtain reliable correlation parameters. The significance level was 5%. The statistical package used was SPSS 24.0 for Windows.

Initially, a descriptive analysis of all study variables was performed. The qualitative variables were presented in terms of their absolute and relative values, and the quantitative variables in terms of their central tendency and dispersion values. The Kolmogorov-Smirnov and Levene tests were used to evaluate the adherence to the normal curve and the homogeneity of the variances, respectively[12].

The Wilcoxon test was used to compare the first and second values of each AOFAS domain since most variables did not present the two principles satisfied above (Non-parametric test). To evaluate the correlation between the SF-36 and the AOFAS domains, in the first and second evaluations, the Spearman correlation coefficient was used (because most of the variables did not present the two principles described above—Non-parametric)[13-15].

The Kappa intraclass correlation coefficient (ICC) was used to evaluate the first and second AOFAS concordance for each domain, with its respective 95% confidence interval. Cronbach's alpha correlation coefficient was used to evaluate internal consistency[13-15].

Results

Fifty patients were interviewed. Table 2 shows the descriptive analysis of age, sex, and diagnosis variables. The results showed that most of the patients were women diagnosed with hallux valgus.

Table 3 shows the mean with standard deviation and the Kappa ICC with a 95% confidence interval and the significance level. An excellent intraclass concordance for all domains was observed.

Table 4 shows the comparison of the first and second AOFAS results for each domain. The results showed no significant

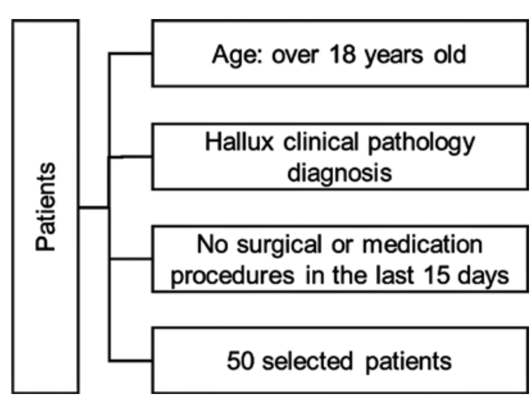

Figure 3. Patient's selection.

Table 2. Descriptive data analysis

Variables	Total (n = 50)
Age (years)	
Mean (SD)	57.20 (12.39)
Minimum - Maximum	28 – 86
Sex (Nº(%))	
Women	36 (72.0)
Men	14 (28.0)
Diagnostic (N(%))	
Rigid hallux	6 (12.0)
Hallux valgus	44 (88.0)

SD: standard deviation

Table 3. Intraclass correlation analysis of AOFAS questionnaire domains

	Pre	Post	ICC (95%CI)	p-value
	Mean (SD)			
Pain	25.0 (10.5)	24.6 (10.3)	0.98 (0.97; 0.99)	< 0.0001
Function	7.6 (2.9)	7.6 (2.9)	0.99 (0.98; 1.00)	< 0.0001
Shoes	6.6 (2.9)	6.6 (2.9)	1.00	< 0.0001
MTP motion	7.4 (3.4)	7.3 (3.4)	0.98 (0.96; 0.99)	< 0.0001
IP motion	3.7 (2.2)	3.9 (2.1)	0.89 (0.82; 0.94)	< 0.0001
Stability	4.6 (1.4)	4.4 (1.6)	0.78 (0.65; 0.87)	< 0.0001
Calus	3.2 (2.4)	3.1 (2.5)	0.96 (0.93; 0.98)	< 0.0001
Alignment	7.4 (4.7)	6.8 (4.6)	0.84 (0.73; 0.90)	< 0.0001
Total	65.5 (23.1)	64.2 (23.0)	0.98 (0.97; 0.99)	< 0.0001

SD: standard deviation; ICC: Intraclass correlation coefficient; 95%CI: 95% confidence interval; p-value: significance level; MTP: metatarsophalangeal; IP: interphalangeal.

difference between the first and second evaluations by the Wilcoxon test in each domain ($p > 0.05$).

Table 5 shows Spearman's correlation analysis of the first and second AOFAS for each domain. A directly proportional correlation was observed between the first and second evaluations in each AOFAS domain.

Discussion

Standardizing an evaluation instrument for hallux injuries is crucial due to the significance of these occurrences. The hallux plays a vital role in balance, support, and strength during walking, jumping, and other foot movements. Treatments with less-than-expected results can cause lasting and potentially limiting compromises in many activities[1,2].

Indeed, instruments that assess progress and outcomes over time are crucial for tailoring the best approach for each patient[3]. Measuring results based on the patient's reports is necessary in orthopedics, especially in foot-related injuries[3].

The AOFAS scoring system is widely used in evaluating outcomes following treatment for ankle and foot injuries. Given that patient input is integral to this assessment, ensuring clear and accurate translation is essential to maintain the integrity and reliability of the results. However, this instrument is not yet available in many languages, and researchers must obtain an adequate linguistic and cultural adaptation[15]. Although widely used to evaluate foot pathologies in Brazil, the AOFAS instrument for hallux pathologies has not yet been translated and culturally adapted into Portuguese.

Table 4. First and second comparison of AOFAS domains

	Pre	Post	Level of significance*
Pain			
Mean (95%CI)	25.0 (22.0; 28.0)	24.6 (21.7; 27.5)	
Standard deviation	10.5	10.3	0.15
Minimum - Maximum	0 – 40	0 – 40	
Function			
Mean (95%CI)	7.6 (6.8; 8.5)	7.6 (6.7; 8.4)	0.32
Standard deviation	2.9	2.9	
Minimum - Maximum	0 – 10	0 – 10	
Shoes			
Mean (95%CI)	6.6 (5.8; 7.4)	6.6 (5.8; 7.4)	1.00
Standard deviation	5	2.9	
Minimum - Maximum	0 – 10	0 – 10	
MTP motion			
Mean (95%CI)	7.4 (6.4; 8.4)	7.3 (6.3; 8.3)	0.32
Standard deviation	3.4	3.4	
Minimum - Maximum	0 – 10	0 – 10	
IP motion			
Mean (95%CI)	3.7 (3.1; 4.3)	3.9 (3.3; 4.5)	0.16
Standard deviation	2.2	2.1	
Minimum - Maximum	0 – 5	0 – 5	
Stability			
Mean (95%CI)	4.6 (4.2; 5.0)	4.4 (3.9; 4.9)	0.15
Standard deviation	1.4	1.6	
Minimum - Maximum	0 – 5	0 – 5	
Calus			
Mean (95%CI)	3.2 (2.5; 3.9)	3.1 (2.4; 3.8)	0.32
Standard deviation	2.4	2.5	
Minimum - Maximum	0 – 5	0 – 5	
Alignment			
Mean (95%CI)	7.4 (6.0; 8.7)	6.8 (5.4; 8.1)	0.19
Standard deviation	4.7	4.6	
Minimum - Maximum	0 – 15	0 – 15	
Total			
Mean (95%CI)	65.5 (58.9; 72.1)	64.2 (57.7; 70.8)	0.04
Standard deviation	23.1	23.0	
Minimum - Maximum	0 – 93	0 – 93	

MTP: metatarsophalangeal; IP: interphalangeal; 95%CI: 95% confidence interval.
* Wilcoxon test.

Table 5. First and second Spearman's correlation coefficient of AOFAS domains

	Pain	Function	Shoes	MTPampli	Ipampli	Stability	Calus	Alignment	Total
Pain	0.97**	0.78**	0.60**	0.61**	0.35*	0.37**	0.59**	0.47**	0.92**
Function	0.75**	0.98**	0.43**	0.54**	0.37**	0.40**	0.48**	0.50**	0.80**
Shoes	0.60**	0.46**	1.00**	0.45**	0.37**	0.37**	0.55**	0.28	0.68**
MTP motion	0.56**	0.52**	0.40**	0.97**	0.61**	0.20	0.30*	0.07	0.65**
IP motion	0.45**	0.42**	0.33*	0.62**	0.89**	0.38**	0.41**	0.43**	0.58**
Stability	0.39**	0.37**	0.38**	0.39**	0.48**	0.80**	0.49**	0.38**	0.47**
Calus	0.65**	0.55**	0.57**	0.29*	0.38**	0.38**	0.96**	0.41**	0.70**
Alignment	0.46**	0.48**	0.32*	0.05	0.26	0.44**	0.40**	0.84**	0.51**
Total	0.91**	0.81**	0.66**	0.66**	0.54**	0.42**	0.68**	0.51**	0.98**

MTP: metatarsophalangeal; IP: interphalangeal; *: p < 0.05; **: p 0.01.

Commonly, a literal translation might be sufficient for many purposes; however, in the healthcare context, a cross-cultural adaptation is crucial to ensure the intended methodology is accurately maintained. This process allows a complete understanding of the instruments without deviations from the language adopted for research[12].

Translating the AOFAS instrument is essential to ensure uniformity in assessment among researchers from different languages and facilitate result comparisons across diverse populations, given its widely recognized effectiveness. However, clarity, reliability, and ease of interpretation are essential standards to uphold during translation. A positive point regarding the AOFAS instrument is that it is short, and the questions are objective, which can be important when seeking translation and cultural adaptation to other languages[16].

It is important to remember that the AOFAS questionnaire has subdivisions to evaluate hindfoot and ankle, midfoot, hallux, and smaller toes, each with specific sub-items for the foot segment under study[11]. The AOFAS Ankle-Hindfoot Scale is the only part already translated and culturally adapted into Portuguese [4]. According to De Boer et al., the Ankle-Hindfoot subdivision is responsive and valid in its original language; however, studies suggested that its translation and validation in other languages still need to be deepened[17].

To evaluate the Ankle-Hindfoot AOFAS, De Boer et al. conducted a study with 118 patients (three follow-up losses), in which they analyzed the reliability, construct validity, reproducibility, and internal consistency. Although the internal consistency was considered inadequate, the subscales were adequate. The validity of the constructs was 82.4% within the study hypotheses, but their longitudinal validity was not seen as appropriate. Their results indicate that the instrument has good results when translated; however, more specific criteria need to be adopted to evaluate results in long-term longitudinal studies[17].

Our study translated the AOFAS Hallux Metatarsophalangeal-Interphalangeal Scale to understand whether the translation can cause negative impacts that can be interpreted inadequately and obtain results different from the reality of each individual evaluated.

This study had a predominantly female population (72%), a mean age of 57.2 years, and 88% with hallux valgus. The epidemiological data follows the literature recognizing hallux valgus as one of the most common diseases affecting the foot, with high prevalence in several epidemiological studies. The prevalence of this disease is known to be higher in women, around 2.3 times higher than in men[18]. The prevalence of hallux valgus is increasing with age, confirmed by studies demonstrating a prevalence of up to 74% in older populations[19].

The intraclass evaluation showed an extremely close concordance and a high reliability coefficient. The interobserver concordance was extremely close, not being total in only two items, "function" (7.6 vs. 7.5) and " metatarsophalangeal motion" (7.4 vs. 7.3). High concordance among the examiners indicates that the questionnaire was well-designed, clear and easy to understand in all phases of the study, both among the researchers and participants. The high result can be further explained due to the quantitative and, therefore, objective assessment, as shown in the study by Rodrigues et al.[2]. The validation and cultural adaptation protocol follows a well-defined flowchart to ensure the quality and applicability of the translation process. These sequential steps ensure that different researchers find similar results when interviewing the same participant, which was achieved in our study.

It is important to verify that when applying the questionnaire for the second time, the same researcher finds results comparable to the first application for the same patient in the same evaluation conditions. In our study, the results among the domains were significantly similar in the first and second evaluations by the Wilcoxon test. All intraclass evaluations had a high concordance, with slightly lower stability and alignment values than the other hallux AOFAS items.

The data in our study reinforce that having a reliable, valid, and reproducible measurement instrument is crucial for orthopedists across different locations to evaluate and compare results qualitatively. To this end, patient-reported outcome scores, such as the AOFAS score, have increased. As an example of using this scoring system, a 2018 Persian-language study evaluated 53 patients with ankle and hindfoot conditions. In this study, Cronbach's alpha coefficient was 0.696, which is considered an acceptable value and a reliable objective subscales test (Kappa). The test-retest reliability measured by the ICC was 0.853 ($p < 0.001$), and the Pearson correlation coefficient between AOFAS and SF-36 was 0.415 ($p = 0.008$). The data showed that the AOFAS Persian translation demonstrated acceptable validity and reliability without cultural adaptation[19]. These data corroborate the success of the questionnaire translation process in the studied population, just like our study, in which the translation proved valid, acceptable, and reproducible.

Conclusions

The data collected affirm that the translation and cultural adaptation of the AOFAS Hallux Metatarsophalangeal-Interphalangeal Scale questionnaire for hallux pathologies were conducted effectively. According to the established criteria, the results showed that the instrument is valid with a very high interobserver concordance and can be safely reproduced in Portuguese.

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Original Article

Investigation of subtle Lisfranc injuries using weight-bearing computed tomography

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Abstract

Introduction: Lisfranc ligamentous injuries are common yet remain a diagnostic challenge. Automated analysis of weight-bearing computed tomography (WBCT) images has been investigated to diagnose various pathologies. However, it has not been studied for Lisfranc ligament injuries. The objective of the study was to examine whether automated WBCT analysis could demonstrate diagnostic utility for these injuries.

Methods: Serial sectioning of Lisfranc complex ligaments was conducted on 24 cadaveric limbs to simulate Lisfranc injuries. WBCT images were collected at each dissection condition under three loading conditions. Images were automatically segmented, and automated measures of specific angles and distances in the midfoot were calculated using digitally reconstructed radiographs. These were analyzed using repeated measures ANOVA and paired T-tests to identify significant differences between dissections at each loading condition.

Results: Overall, minimal differences between dissection conditions were observed in automatically generated measures. Differences in axial angles of the metatarsals in severe dissections were observed, and there were fewer differences in angular measures across dissection conditions in fully loaded than unloaded conditions.

Conclusions: Automated analysis of WBCT images may indicate severe Lisfranc ligamentous injury but is insufficient to diagnose ligament injuries without full capsule disruption. This lack of injury markers may be due to the imaging conditions, automated analysis, or biomechanics of Lisfranc injuries. More alignment differences were seen under unloaded conditions, suggesting that weight-bearing imaging may not be appropriate for this injury. Overall, automated analysis shows only minimal changes in alignment measures, and additional study is necessary to improve diagnostic tools for Lisfranc injuries.

Evidence Level V; Mechanism-based reasoning.

Keywords: Lisfranc injury; Lisfranc diagnostics; Weight-bearing computed tomography; Midfoot biomechanics.

Introduction

Lisfranc injuries are the second most common athletic foot injuries due to direct high-energy trauma or low-energy forces applied to a plantar flexed foot[1-4]. Lisfranc injuries are defined as injury to the Lisfranc ligamentous complex (LLC), which consists of dorsal, interosseous, and plantar ligaments that interconnect the medial and intermediate cuneiform (C1 and C2) and first and second metatarsals (M1 and M2). The LLC is a dynamic functional unit through which multiple ligaments and joints contribute to the stability of the midfoot, and injuries to a component of this complex may destabilize the midfoot, causing differences in observed bony alignment[5-7]. The transverse arch within midfoot architecture requires a tensile load for stabilization and articulation with the forefoot. This tension is supplied by the dorsal, interosseus, and plantar ligaments, all of which connect the

Study performed at the University of Utah, Salt Lake City, USA.

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C1 and M2[5,8-11]. This ligamentous support is critical for proper alignment between the midfoot and forefoot during movement. The plantar ligament has been shown to be the largest contributor to midfoot stability, and often, injuries involving this section of the complex predispose to instability that requires surgical correction[5,11,12]. Given the complexity and translational relationship of the LLC, low-energy injuries to isolated portions of this complex may not cause substantial differences in the overall structure of the midfoot.

Due to this complexity, Lisfranc injuries are a diagnostic challenge, with an estimated 20% of injuries being misdiagnosed at initial presentation[13]. Misdiagnosis may lead to delay in treatment and potentially worse long-term outcomes[7,14,15]. The most common clinical tool for Lisfranc injury diagnosis is measuring the distance between the C1 and M2 as seen on bilateral weight-bearing radiographs[6,16-19]. However, radiographs lack interpretation of 3D joint relationships, which seems compromised in Lisfranc injuries. Weight-bearing computed tomography (WBCT) is an acceptable modality to diagnose Lisfranc injuries, but 3D analysis of WBCT images is limited by computational time and personnel requirements[20,21]. Recently, automatic image segmentation and 3D measurement analysis (Bonelogic, Disior, Paragon 28, Englewood, CO) have been proposed as a solution to these challenges and have been investigated in various foot and ankle pathologies. This analysis has not been studied for Lisfranc injury diagnosis, and beyond its utility as a diagnostic tool, it may provide insight into the mechanical function of the LLC ligamentous components in stabilizing the midfoot.

The objective of this study is to examine differences in automatically generated measurements in simulated cadaveric Lisfranc injuries to determine the feasibility of this analysis as an adjunct diagnostic tool.

METHODS

Specimen preparation

After approval from the Institutional Review Board, 24 through-knee cadaveric specimens (12 matched pairs) were obtained for the study. Inclusion criteria included male cadavers ages 18 to 65 years with a body mass index (BMI) of less than 30. Exclusion criteria disqualified individuals with previous foot and ankle injuries, neoplastic bone involvement, or surgeries to the lower extremity. An external fixator consisting of an Ilizarov apparatus using four 1.5 mm Kirschner wires held in a radiolucent frame was attached to each specimen to keep them in a plantigrade position[22,23].

Serial dissections

To simulate reproducible isolated Lisfranc ligamentous injuries, a stepwise serial dissection of the Lisfranc complex was carefully performed by a board-certified fellowship-trained orthopedic surgeon. The process began with a dorsal incision to visualize and confirm the intact Lisfranc complex. The serial dissection occurred in the following order: dorsal ligament connecting C1 to M2 (Condition D1), interosseous ligament connecting C1 to M2 (Condition D2), and plantar ligament connecting C1 to M2 and M3 (Condition D3). The initial three conditions simulated individualized interruption of the three primary stabilizing components of the Lisfranc complex[10]. After serial dissection of these three main components, the capsules of the first and second tarsometatarsal joints (TMT1 and TMT2, respectively) and the medial-middle inter-cuneiform ligament were dissected in a randomized order (Condition CD). This condition involved the complete dissection of midfoot Lisfranc joint soft tissue support structures and was used for statistical comparison of a fully dissected ligament complex, even though it is not representative of a typical injury mechanism.

Image acquisition

Before dissection and following each dissection step (conditions D1-CD), WBCT scans were acquired under three weight-bearing (loading) conditions. The load was applied using weights placed on top of the external fixator. The three loading conditions were unloaded (0 kg), partially loaded (40 kg), and fully loaded (90 kg). The load amounts were chosen to provide a reasonable estimation of body weight while conserving the specimen for serial dissection and imaging. WBCT images were collected using a pedCAT (CurveBeam LLC; medium view, 0.3 mm slice thickness, 0.3 mm slice interval, kVp 120, mAs 22 – 62), totaling 360 WBCT images.

Image segmentation and analysis

After WBCT images were obtained with all dissection and loading conditions, images were segmented automatically from manually labeled seed points on each bone (Bonelogic, DISIOR, Paragon 28, Englewood, CO). 3D models were exported from these segmentations and manually inspected for accuracy (Mimics, Materialize, Leuven, Belgium). Segmented images were used to generate digitally reconstructed radiographs and automatically calculate specific angle and distance measurements in the midfoot (Bonelogic, DISIOR, Paragon 28, Englewood, CO). The nine midfoot measurements calculated and analyzed were the M1-M2 intermetatarsal angle in the axial and sagittal planes, TMT1 and TMT2 angles in the axial and sagittal planes, TMT1 minimum joint space, M1 torsion, and M1 internal rotation (Figure 1).

Data analysis

A repeated measures ANOVA was used to examine differences between dissection conditions for each outcome variable at each loading condition. The repeated measures ANOVA was chosen due to a stepwise progression through dissection conditions, where there are more dissected ligaments at each subsequent condition. By comparing each measure to earlier measures of the same specimen, the repeated measures ANOVA normalizes data and accounts for within-subject variability to provide a more accurate data analysis than a traditional ANOVA[24]. ANOVA analysis

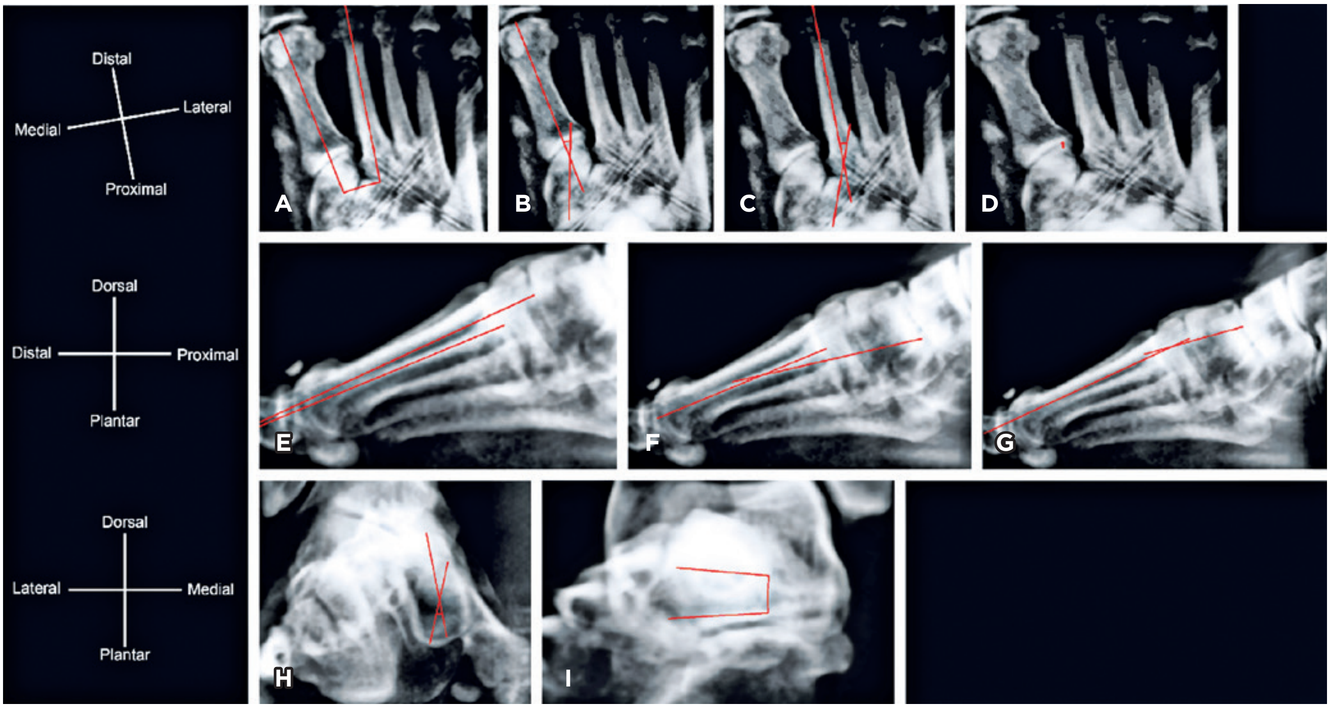

Figure 1. Digitally reconstructed radiographs from DISIOR showing the automatically calculated measures of (A) axial plane angle between the first and second metatarsal, (B) axial plane angle between the medial cuneiform and first metatarsal (first tarsometatarsal joint), (C) axial plane angle between the intermediate cuneiform and second metatarsal (second tarsometatarsal joint), (D) minimum joint space in the first tarsometatarsal joint, (E) sagittal plane angle between the first and second metatarsals, (F) sagittal plane angle of the first tarsometatarsal joint, (G) sagittal plane angle of the second tarsometatarsal joint, (H) first metatarsal torsion, and (I) first metatarsal internal rotation.

used a significance value of α = 0.05. Following the repeated measures ANOVA, all combinations of outcome variables and loading conditions that showed a significant difference between dissection conditions were further analyzed using paired t-tests as a post-hoc analysis to compare each combination of dissection conditions. This step provides a detailed understanding of which injury types could be differentiated using each output condition. While existing studies using DISIOR typically use a significance value of 0.05[25,26], these post-hoc paired t-tests used a significance value of α = 0.01 due to the high number of comparisons made in this analysis. This does not reflect a mathematical correction, as a Bonferroni correction is too conservative for this use, but it does reduce the likelihood of false significance findings[27]. Using paired t-test for this post-hoc analysis retains the within-subject comparison of the repeated measures ANOVA and determines at what points the differences are significant, not just which outcomes had significant change at some point in the dissection. This effectively tests not just the mechanical changes to the joint structure but also the severity of injury needed to identify the injury using these methods. Statistical tests were conducted using raw data because both the repeated measures ANOVA and paired t-tests intrinsically account for within-subject variability, but data was normalized for graphical representation to illustrate the changes between conditions better.

Results

Repeated measures ANOVA showed significant differences between dissection conditions for the TMT1 axial angle in all three loading conditions, the TMT2 axial angle in all three loading conditions, and both the intermetatarsal axial angle and the M1 sagittal angle at the unloaded condition only. All other outcome variables did not show statistically significant differences among dissection conditions at any loading condition. The mean and standard deviation for all outcome measures at each dissection and loading condition are given in Table 1, and all p-values for repeated measure ANOVA tests for differences between any two dissection conditions at each loading condition are given in Table 2.

Post-hoc analysis of the intermetatarsal sagittal angle in the unloaded condition showed a significant difference between the complete dissection condition (CD) and each of the other dissection conditions (D1, D2, and D3) but not the undissected condition (UND). The intermetatarsal angle

Table 1. Mean and standard deviation (SD) for each outcome measure under each combination of loading and dissection conditions.

		M1-M2 Axial		M1-M2 Sagittal		TMT1 Sagittal		TMT2 Sagittal		TMT1 Axial		TMT2 Axial		M1 Torsion		M1 Rotation		TMT1 Min Joint Space	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Unloaded	UND	10.12	2.90	1.27	2.40	9.12	2.84	6.08	3.18	-24.85	3.09	-23.89	4.96	17.65	5.30	-3.42	7.95	1.12	0.10
	D1	10.19	2.77	1.26	2.50	9.31	2.92	6.24	2.79	-24.79	3.02	-23.72	4.73	17.53	6.54	-2.38	5.72	1.14	0.16
	D2	10.08	2.88	1.01	2.60	10.08	3.69	6.83	2.91	-24.51	3.04	-23.63	4.86	17.74	7.62	-2.97	7.81	1.17	0.13
	D3	10.23	2.80	1.16	2.53	9.80	2.46	6.71	2.91	-24.30	3.69	-23.18	5.02	18.38	7.47	-2.19	6.62	1.15	0.10
	CD	9.82	2.48	2.15	2.41	9.01	2.82	6.81	2.70	-23.04	4.25	-22.76	5.00	17.39	12.37	-2.07	12.89	1.20	0.11
Partially Loaded	UND	10.49	3.00	1.67	2.35	9.12	2.75	6.44	2.85	-24.62	3.19	-23.42	4.94	17.19	7.24	-2.53	8.98	1.12	0.13
	D1	10.59	2.95	1.74	2.38	9.12	2.71	6.59	2.91	-24.67	3.05	-23.30	4.95	18.20	8.13	-4.57	12.50	1.15	0.13
	D2	10.71	2.98	1.73	2.41	9.46	2.93	6.91	2.62	-24.34	3.22	-23.03	4.91	17.96	7.35	-1.08	7.98	1.17	0.08
	D3	10.74	2.81	1.73	2.34	9.60	2.57	6.92	2.73	-24.10	3.58	-22.92	5.00	18.21	7.11	-3.30	8.09	1.15	0.09
	CD	10.62	2.63	1.96	2.19	9.28	3.06	6.71	2.70	-23.82	4.39	-22.74	5.23	19.43	8.82	-4.22	6.56	1.16	0.08
Fully Loaded	UND	10.73	2.96	1.92	2.33	8.96	2.78	6.63	2.79	-24.80	3.31	-23.25	5.06	17.41	5.84	-2.91	5.22	1.13	0.13
	D1	10.81	2.90	1.76	2.33	9.27	2.81	6.58	2.98	-24.63	3.28	-23.18	4.96	17.47	6.47	-2.46	7.86	1.12	0.13
	D2	10.80	2.98	1.71	2.40	9.48	2.99	6.97	2.47	-24.26	3.48	-22.81	5.08	18.10	7.99	-3.79	8.58	1.11	0.15
	D3	10.84	2.87	1.72	2.41	9.57	2.93	6.91	2.76	-23.95	3.74	-22.67	5.17	17.21	6.03	-2.04	7.99	1.10	0.23
	CD	10.51	2.68	2.02	2.31	9.26	3.35	6.83	2.76	-23.74	4.95	-22.64	5.39	17.37	12.63	-2.20	12.46	1.14	0.10

C1: Medial cuneiform; C2: Intermediate cuneiform; M1: First metatarsal; M2: Second metatarsal; TMT1: First tarsometatarsal; TMT2: Second tarsometatarsal.
Serial dissection conditions consist of undissected (UND), dissection of C1-M2 dorsal ligament (D1), dissection of C1-M2 interosseous ligament (D2), dissection of C1-M2 and M3 plantar ligament (D3), and complete dissection of the TMT1 and TMT2 joint capsules and the medial-middle inter-cuneiform ligament (CD).

Table 2. P-values for repeated measures ANOVA of each outcome value and loading condition across the four dissection conditions. Tests showing statistical significance are in bold and represent any outcome measure under a specific loading condition with a significant difference between at least two of the five dissection conditions.

Outcome Measure	Unloaded	Partially Loaded	Fully Loaded
Intermetatarsal axial angle	0.170	0.404	0.347
Intermetatarsal sagittal angle	**0.002**	0.205	0.352
TMT1 axial angle	**< 0.001**	**0.034**	**0.044**
TMT1 sagittal angle	**0.035**	0.136	0.225
TMT2 axial angle	**< 0.001**	**0.010**	**0.024**
TMT2 sagittal angle	**0.013**	0.184	0.307
TMT1 rotation	0.837	0.269	0.762
TMT1 torsion	0.795	0.283	0.853
TMT1 minimum joint space	0.058	0.361	0.684

TMT1: First tarsometatarsal; TMT2: Second tarsometatarsal.

value was significantly greater in condition CD than in the other three dissection conditions. The TMT1 sagittal angle in the unloaded condition showed a significant difference between the UND and dissection D3, where the angle was greater in dissection D3 than in the UND. P-values for each of these comparisons are given in Table 3.

Post-hoc analysis of the TMT1 axial angle at the unloaded condition yielded a significantly increased angle axial angle in dissection condition CD than in each other dissection condition, including the UND. However, there were no significant differences between dissection condition CD and any other dissection condition in the partially and fully loaded conditions. In the partially loaded condition, the angle was significantly greater under dissection condition D3 than condition D1. In the fully loaded condition, conditions D2 and D3 had significantly greater angle measurements than condition D1. P-values for the TMT1 post-hoc tests of all three loading conditions are given in Table 4.

Post-hoc analysis of the TMT2 axial angle in the unloaded condition revealed significantly greater angle measurements in dissections D3 and D4 than in the UND or dissection D1. The significant increase in axial angle between the UND and conditions D3 and D4 was also present in the partially loaded condition. There were significant differences between dissection condition D3 and the UND and condition D1 in the fully loaded state. P-values for the TMT2 post-hoc tests in all three loading conditions are given in Table 4.

Discussion

Given the difficulties in subtle Lisfranc injury diagnosis and the long-term implications of missed injuries, an improvement in diagnostic methods is needed. Automated analysis pipelines may overcome the logistical barrier preventing 3D image analysis, but thus far, they are not effective as adjunctive diagnostic tools. This study investigated automatically generated measures of 3D alignment as indicators of simulated presence and severity of Lisfranc injury. Several individual joint angles within the midfoot showed significant differences with simulated Lisfranc injuries, but the change in these outcome measures was minimal. Most of the significant differences were seen in comparisons that included the complete dissection (CD) condition, and no outcome measures showed significant differences between all sequential ligament dissections. While several outcome measures showed significant differences between CD and UND or CD and early dissection conditions (D1 or D2), these differences are not clinically relevant because the CD condition is not representative of a known injury mechanism.

Table 3. Post-hoc analysis of the intermetatarsal sagittal angle, first tarsometatarsal sagittal angle, and second tarsometatarsal sagittal angle in the unloaded condition showing p-values from paired t-tests comparing each pair of dissection conditions. Tests showing statistical significance are in bold.

Comparison	Intermetatarsal sagittal angle	TMT1 sagittal angle	TMT2 sagittal angle
UND – D1	0.878	0.372	0.485
UND – D2	0.104	0.024	**0.003**
UND – D3	0.475	**0.003**	0.015
UND – CD	0.015	0.786	0.024
D1 – D2	0.136	0.075	0.020
D1 – D3	0.432	0.019	0.036
D1 – CD	**0.008**	0.435	0.026
D2 – D3	0.413	0.519	0.915
D2 – CD	**0.002**	0.037	0.770
D3 – CD	**0.002**	0.042	0.684

C1: Medial cuneiform; C2: Intermediate cuneiform; M1: First metatarsal; M2: Second metatarsal; TMT1: First tarsometatarsal; TMT2: Second tarsometatarsal.
Serial dissection conditions consist of undissected (UND), dissection of C1-M2 dorsal ligament (D1), dissection of C1-M2 interosseous ligament (D2), dissection of C1-M2 and M3 plantar ligament (D3), and complete dissection of the TMT1 and TMT2 joint capsules and the medial-middle inter--cuneiform ligament (CD).

No outcome measures showed significant differences between UND and D1, and only TMT2 axial and sagittal angles showed significant differences between UND and D2. However, neither measure showed significance between D2 and any other dissection condition. TMT1 sagittal and TMT2 axial angles showed significant differences between UND and D3, and the TMT2 axial angle additionally had a significant difference between D1 and D3 with a trend of decreasing magnitude of this angle measure with progressive dissection conditions while unloaded. More significant differences were observed under unloaded conditions than in partially or fully loaded conditions. This contradicts the belief that weight-bearing imaging improves diagnostic accuracy and suggests that load may stabilize the midfoot and mask subtle structural changes.

The poor ability of this analysis to distinguish between simulated subtle injury conditions may be caused by many factors. As mentioned, weight-bearing imaging may not be ideal for identifying Lisfranc injuries. The outcome measures tested in this study were chosen based on ease of use, as they are the automatically generated midfoot measures from this software with the assumption that manually calculated 3D measures would not be clinically transferrable due to the time and skill needed to complete a manual analysis. However, these measures may not be the most effective for identifying the alignment change caused by subtle Lisfranc injuries. Further, bony alignment may be a poor measure of Lisfranc complex stability under any imaging modality or analysis technique. The midfoot is a highly biomechanically stabilized joint, with redundancy in stabilization through the many articulations and ligaments in the Lisfranc complex and surrounding areas of the foot[8]. Without substantial change in bony alignment, the challenges of Lisfranc diagnosis from radiographs would not be remedied by computed

Table 4. Post-hoc analysis of the first and second tarsometatarsal axial angles at each loading condition showing p-values from paired t-tests comparing each pair of dissection conditions. UND represents the undissected condition, and D1, D2, D3, and CD represent the serial dissection conditions. Tests showing statistical significance are in bold.

Comparison	TMT1 Axial Angle			TMT2 Axial Angle		
	Unloaded	Partially Loaded	Fully Loaded	Unloaded	Partially Loaded	Fully Loaded
UND - D1	0.619	0.043	0.428	0.095	0.257	0.517
UND - D2	0.049	0.033	0.025	0.189	0.017	**0.002**
UND – D3	0.087	0.014	0.030	**0.001**	**0.004**	**0.001**
UND – CD	**< 0.001**	0.036	0.057	**< 0.001**	**0.003**	0.024
D1 – D2	0.108	0.016	**0.006**	0.640	0.078	0.016
D1 – D3	0.122	**0.009**	**0.004**	**0.006**	0.021	**0.002**
D1 – CD	**< 0.001**	0.036	0.055	**0.003**	0.028	0.063
D2 – D3	0.491	0.191	0.127	0.054	0.533	0.419
D2 – CD	**0.002**	0.162	0.231	0.010	0.268	0.565
D3 - CD	**0.001**	0.338	0.590	0.076	0.335	0.885

C1: Medial cuneiform; C2: Intermediate cuneiform; M1: First metatarsal; M2: Second metatarsal; TMT1: First tarsometatarsal; TMT2: Second tarsometatarsal.
Serial dissection conditions consist of undissected (UND), dissection of C1-M2 dorsal ligament (D1), dissection of C1-M2 interosseous ligament (D2), dissection of C1-M2 and M3 plantar ligament (D3), and complete dissection of the TMT1 and TMT2 joint capsules and the medial-middle inter-cuneiform ligament (CD).

tomography imaging. More accurate diagnostic imaging may require soft tissue imaging modalities.

Previous research has demonstrated that the plantar ligament of the LLC is important in providing midfoot stability and that disruption of this ligament likely contributes to the instability of the midfoot that necessitates surgical fixation(5,11,28). This importance of the plantar ligament is supported by our data showing significant changes from the UND in TMT1 sagittal and TMT2 axial angles only in conditions where the plantar ligament had been dissected (dissection conditions D3 and D4). While these data suggest that the TMT1 sagittal and TMT2 axial angles may be relevant for diagnosing more severe Lisfranc injuries, the lack of difference to other dissection conditions is concerning because the angles may not be different enough for identification without having an uninjured control for comparison. Further, the more severe Lisfranc injuries are less likely to be missed using current diagnostics than subtle injuries, so the analysis may not be worthwhile if it can only identify severe injuries that may be seen using simpler diagnostic tools.

Weight-bearing imaging is commonly believed to be superior to non-weight-bearing imaging in the foot and ankle(8,29,30). However, these data contradict this theory as there were a greater number of significant differences in outcome measures under unloaded conditions than under partially or fully loaded conditions, which may be due to the ability of the midfoot to distribute static load across bone rather than soft tissue to ensure proper alignment across dynamic movement. This indicates that non-weight-bearing imaging may have a role in investigating Lisfranc injury diagnostics.

While this study offers insight into the pathological changes in midfoot angles in Lisfranc Injuries, several limitations exist. The automatic analysis software used for this study has not been robustly validated. Studies have shown promising reliability between automatically generated and manually calculated measurements, but the image segmentations used to calculate these measures have not been validated(31-33). Additionally, some potentially valuable measures, such as rotation of the TMT2 joint, were not available. However, the objective of this study was to observe if the automatic analysis, even with unknown intrinsic error, would prove to be a useful diagnostic tool. The comparisons made in this analysis are to undissected conditions of the same specimen and thus normalize for much of the population variation in midfoot alignment, but comparisons of these actual measures to population means may not be appropriate. This study did not investigate using an uninjured contralateral limb as a control for comparison, but that may be a way to alleviate this concern. As previously mentioned, the complete dissection condition (CD) did not represent a known injury mechanism, as Lisfranc injuries involving both the inter-cuneiform ligament and TMT capsule are uncommon(12,34). While it is a beneficial statistical comparison for this analysis, this dissection condition has limited application for understanding clinical presentation. Cadaveric models with simulated injuries are limited by their lack of active muscle contractions that may contribute to detecting Lisfranc injuries and by the absence of comorbid foot deformity or additional injury that may complicate the findings for a subtle Lisfranc injury.

Conclusion

Automatic analysis of 3D imaging is an exciting advancement that may allow for more detailed clinical analysis of foot alignment for subtle injury diagnosis. However, these data do not support using this technology as an adjunct diagnostic tool for Lisfranc injuries. This may be due to the outcome measures included in this analysis, the potential masking of injury under weight-bearing, or the mechanism of the injury itself. These data support further investigation of the role of weight-bearing vs non-weight-bearing imaging in midfoot injuries and the potential utilization of non-bony imaging methods to improve Lisfranc injury diagnosis.

Authors' contributions: Each author contributed individually and significantly to the development of this article: SME: Study design, image processing of weightbearing CT data, data analysis, manuscript writing; MRR: Data analysis, statistical analysis, manuscript writing; TJR: Study design, image processing of weightbearing CT data, data analysis; RJL: Technical assistance, MATLAB coding, data analysis; YS: Study design, cadaveric experimental data acquisition, weightbearing CT acquisition, manuscript writing; NK: Study design, clinical interpretation, manuscript writing; ALL: Study design, data analysis, image processing, data interpretation, manuscript writing. All authors read and approved the final manuscript.*ORCID (Open Researcher and Contributor ID) iD.

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Original Article

Intramedullary nailing as osteosynthesis technique for the fibula in total ankle arthroplasty via lateral approach

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Abstract

Objective: To describe a variation in the final osteosynthesis technique for total ankle replacement (TAR) implantation through lateral approach.

Methods: We retrospectively reviewed a series of cases dated between January 2022 and May 2023 in which intramedullary nailing was used as the osteosynthesis technique for the fibula during TAR implantation via lateral approach.

Results: In all cases, skin scarring and soft tissue recovery to baseline were achieved in one and a half month to three months. Consolidation of the fibula occurred at an average of three months. No material was removed in any of the cases to date. Finally, patients were satisfied, resuming their previous activities.

Conclusion: To our knowledge, this study is the first to investigate a modification of the osteosynthesis technique in the lateral approach to TAR. We believe the intramedullary nail for the fibula may be a useful tool to prevent soft tissue complications, requiring prospective and comparative studies to evaluate its efficacy.

Level of Evidence IV; Therapeutic Studies; Case Series.

Keywords: Total ankle replacement; Soft tissue complications; Osteosynthesis technique; Fibula.

Introduction

The advent of modern total ankle replacement (TAR) led to an exponential increase in the use of this emerging technology over the past two decades in the United States and abroad[1,2]. Although mechanical and instrumental design has improved with recent designs[3,4], perioperative skin and soft tissue complications remain a concern[5,6].

It has been reported that wound complications occur in 6.6% to 28% of patients after total ankle arthroplasty[7,8]. Soft tissue impairment following TAR, in the form of dehiscence or wound failure, may lead to potentially devastating consequences, such as periprosthetic infection, implant failure, and amputation, which is the most feared sequela.

The purpose of the present study is to describe a variation in the final osteosynthesis technique for TAR implantation through lateral approach. We hypothesize that using an intramedullary nail as osteosynthesis technique for the fibula in the lateral approach can reduce soft tissue problems and consequently decrease the current rate of related reintervention.

Methods

All TARs were performed at our institution, by foot and ankle surgeons with extensive experience in TAR. The most used TAR design at our center is the Trabecular Metal™ Total Ankle (Zimmer Biomet – Zimmer, Waesaw, Indiana, USA) via lateral approach. After obtaining institutional review board approval, we retrospectively reviewed a series of cases dated between January 2022 and May 2023 in which intramedullary nailing was used as the osteosynthesis technique for the fibula during TAR implantation via lateral approach. The intramedullary nail used was the fibular nail system by Acumed® (Hillsboro, Oregon) (Figure 1). The rest of the surgical technique was developed as described in protocols, with the use of an external fixator and intraoperative radiological control, only changing the final fibular synthesis technique.

This case series includes six patients with clinical follow-up of at least six months and at most one and a half year. Preoperative patient demographics, comorbidities, smoking

Study performed at the Hospital Complex of Santiago de Compostela, Santiago de Compostela, Galicia, Spain.

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status, American Society of Anesthesiologists (ASA) score, and body mass index (BMI) were analyzed.

Postoperatively, all patients were placed in a non-weight-bearing short-leg cast for four weeks. Thereafter, weight-bearing was allowed wearing a controlled ankle movement (CAM) walking boot as tolerated by patients, and all patients participated in a rehabilitation program. Clinical outcomes, including wound healing, fibular consolidation, and range of motion, were recorded. Similarly, outcomes were recorded in terms of patient satisfaction, residual pain, and return to previous baseline activity. Pain was assessed using a visual analog scale (VAS) ranging from 0 (no pain) to 100 (maximum pain).

Results

The average age in the six cases presented was 65 years (range 60 to 78), the average BMI was 29.5, and the smoking rate was zero. Five of the six cases had an ASA score of II, while the sixth patient was 78 years old and had an ASA score of III. Four of the six cases had two days of hospitalization, while the remaining two cases were hospitalized for 4 to 6 days solely due to poor pain control. In all cases, only one ischemia was required, so that in none of the cases the operation time exceed two hours.

In all cases, skin scarring and soft tissue recovery to baseline were achieved sometime between one and a half month and three months. None of the cases required additional surgery, and only one case used a wearable negative pressure dressing (Avelle® – Convatec, Ciudad Autónoma de Buenos Aires, Argentina) for one week.

Consolidation of the fibula occurred at an average of three months. Only in one case did the consolidation of the fibula collapse. No complaints related to the osteosynthesis material were reported in any of the cases, and no material was removed in any of the cases to date. Finally, in all cases, patients were satisfied, achieving 20 grades of motion and resuming their previous activities.

Discussion

TAR has been increasing in popularity as an alternative to arthrodesis for the management of ankle arthritis[9,10], but postoperative wound complications and soft tissue instability can be a challenging clinical scenario. The skin of the dorsal ankle can be unyielding because it has limited mobility after surgery; it is also thin and lacks significant muscle mass[11]. For this reason, even minor wounds can expose the underlying tendons and neurovascular structures, which in turn can lead to deep infections and implant failure. On the other hand, intramedullary nailing is a minimally invasive technique that provides stable fixation and reduces the risk of soft tissue complications[12]. Therefore, in this report, we used this osteosynthesis technique with the aim of reducing the rate of soft tissue complications reported in literature. The main advantage of this technique is that it is not a plate with

Figure 1. Anteroposterior (A) and lateral (B) projections of Trabecular Metal™ TAR and fibular nail system postoperative control.

screws that protrudes on the skin and may cause discomfort, but an intramedullary system. This may be related to the fact that no patient in our series experienced discomfort with the osteosynthesis material, and none of these had to be removed. One of the concerns after osteotomy is nonunion. At follow-up three months after surgery, we confirmed bone union at the osteotomy site.

In addition, tourniquets are commonly used in foot and ankle surgery, and, although the time at which a tourniquet is applied has not been associated with serious wound complications in the foot and ankle, it has been widely discussed in total knee arthroplasty[13,14]. For this reason, Gross et al. [6] advocate limiting tourniquet time. In this sense, the use of an intramedullary nail instead of an osteosynthesis plate did not lead to an increase in operative time, since none of the cases required a surgical procedure lasting more than two hours.

Regarding the smoking status, Known et al.[15] published the first data showing an association between smoking and prolonged hospitalization after TAR. Whalen et al.[8] studied 57 consecutive total ankle arthroplasties with a wound complication rate of 28%. Analysis of various risk factors included cardiovascular disease, peripheral vascular disease, and a smoking history of more than 12 pack-years. In contrast, none of the patients in our case series were recorded as smokers, so smoking could be excluded as a cause of soft tissue complication and prolonged hospitalization in our series.

In the end, this study has several limitations. First, it is a retrospective study of a series of cases, with all the associated weaknesses. No control group was formed to allow comparison with other established forms or treatment tools. Finally, the population collected is heterogeneous in terms of age and level of previous activity; it is also a short series of patients.

Conclusions

To our knowledge, this study is the first to investigate a modification of the osteosynthesis technique in the lateral approach to TAR. We believe that the intramedullary nail for the fibula may be a useful tool to prevent soft tissue complications, requiring prospective and comparative studies to evaluate its efficacy.

Authors' contributions: Each author contributed individually and significantly to the development of this article: ACC *(https://orcid.org/0000-0002-6827-8688) Conceived and planned the activity that led to the study, wrote the article, participated in the review process; PDD *(https://orcid.org/0009-0004-8393-901X) Data collection, bibliographic review; LAM *(https://orcid.org/0000-0002-4196-5218) Formatting of the article, bibliographic review; CAV *(https://orcid.org/0009-0008-1417-5529) Interpreted the results of the study, participated in the review process; Performed the surgeries; data collection, statistical analysis. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Original Article

Epidemiological study of patients with diabetic foot

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Abstract

Objective: Describe the epidemiological profile of patients with diabetic foot registered and followed in an orthopedic outpatient clinic.

Methods: A retrospective study was conducted, analyzing the medical records of 500 patients. The reason for the initial consultation, age, smoking, alcoholism, body mass index, sex, type of diabetes, and need and type of surgery were analyzed.

Results: The reason for the initial consultation was foot ulcer in 198 patients (39.6%), followed by infection in 122 (24.4%). One hundred and twenty patients (24%) had Charcot arthropathy and 60 (12%) diabetic neuropathy. Most patients were male (67.2%), and the mean age was 65 years, with almost 70% over 50 years in initial care. The mean body mass index was 26.11. Most patients reported being non-smokers (81.4%) and non-alcoholics (85.2%). Type II diabetes predominated (94.4%). Amputations were performed in 306 patients (81.4%) at some point during outpatient follow-up, being classified as minor in 182 patients (59.5%) and major in 124 (40.5%).

Conclusion: Most patients at the diabetic foot outpatient clinic are men aged over 50 years, non-smokers and non-alcoholics, and with a slightly high body mass index of 26.1. They have already attended the outpatient clinic with foot complications and suffered some level of foot amputation.

Level of Evidence IV; Therapeutic Studies; Case Series.

Keywords: Diabetic foot; Epidemiology; Complications.

Introduction

Diabetes Mellitus is a chronic disease with high prevalence in Brazil and worldwide[1-3]. In 2021, according to the International Diabetes Federation, one in ten adults had diabetes. According to the organization, diabetes in adults between 20 and 79 years old tripled between 2000 (4.6% worldwide) and 2021 (10.5% worldwide). In Brazil, this number is estimated to be 15.7 million[4].

Among the complications, peripheral arterial disease and neuropathy are responsible for diabetic foot syndrome, which includes ulcers, Charcot arthropathy, and infection that may end in amputation[1]. The importance of diabetic foot extends beyond the impact on individuals; it is also a public health concern[5,6]. Almost 25% of health expenditures in the diabetes population are due to foot complications. It is estimated that, annually, in the US and the UK, this expenditure reaches 11 billion dollars and almost half a billion dollars, respectively[7]. In Brazil in 2014, this expenditure exceeded 500 million reais[8]. Investing in preventing diabetic foot is deemed essential for mitigating associated complications and reducing consequent healthcare expenses[3,5]. According to Al-Rubeaan et al.[7], implementing programs to prevent diabetic foot syndrome can reduce the amputation rate by up to 70%.

The medical records of patients registered in the foot and ankle group were evaluated to understand the profile of patients who attend the diabetic foot outpatient clinic at our institution and to outline an adequate prevention program for the future. The initial impression is that the patients who attend our outpatient clinic are, for the most part, type II

Study performed at the Grupo de Cirurgia do Pé e Tornozelo; Departamento de Ortopedia e Traumatologia da Santa Casa de Misericórdia de São Paulo, São Paulo, SP, Brazil.

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diabetics, obese, and smokers, and the attendance is already to treat some complications, and they do not fit into a prevention program for wound and foot amputation.

The objective of the study is to describe the epidemiological profile of patients with diabetic foot registered and followed in an outpatient clinic of the foot and ankle group of the Department of Orthopedics of Santa Casa de Misericórdia de São Paulo.

Methods

This study was approved by the Institutional Review Board under the number 69935823.3.0000.5479. The first 1000 patients registered at the outpatient clinic were analyzed. The data collected were obtained from the medical records routinely updated at each new consultation.

The following data were analyzed: the age the patient started follow-up at the outpatient clinic, sex, type of diabetes, body mass index (BMI), habits (smoking and alcoholism), regular control of diabetes, use of insulin therapy, history of ulcers (evaluating the site of lesions and possible recurrences), presence of Charcot arthropathy and its classifications (anatomical and evolutionary of Einchenholtz)[9-12], and previous surgery. Other diabetes-related factors were also noted, such as ophthalmological, renal, and vascular disorders, which were reported by the patient. If amputation was performed, what was the reason for it, and what was the level of amputation. The reason for initial care was also documented and classified into peripheral neuropathy (only loss of sensation without other disorders), ulcer, infection, or Charcot arthropathy. When there were two of these disorders in the initial care, we considered this reason in the following order: Charcot arthropathy, infection, ulcer, and loss of sensation.

The BMI was calculated based on the weight performed at the patient's last visit. Six groups were considered: underweight, BMI less than 18.5; ideal weight, BMI between 18.6 and 24.9; slightly overweight, BMI between 25.0 and 29.9; grade I obesity, BMI between 30.0 and 34.9; grade II obesity, BMI between 35.0 and 39.9; and grade III obesity (morbid), BMI above 40. The patients were considered smokers when they declared smoking daily. The patients were considered alcoholic when there was daily declared alcohol intake. Adequate regular control of diabetics was defined as clinical outpatient visits every four months at least. Recurrent ulcer was defined as the appearance of a new ulcer in the same foot with previous involvement, regardless of whether or not it was on the same topography as the last. Appropriate footwear was considered when the patient came to the outpatient clinic with the correct shoe, insole, or orthosis suitable for the level of amputation. Charcot arthropathy and its classifications were detected from the changes seen on the foot and ankle radiographs (in amputees, the radiographs before amputation were considered). Minor amputation was defined when part of the foot was preserved, while major amputation was considered when amputation was performed at the level of the tibia or more proximal. Ophthalmological and renal disorders were determined by the self-declaration of any problem that the person feels regarding the vision and any diagnosis by other medical services related to the urinary tract.

Patients without written records or with incomplete data, those who did not return after the first consultation, or those who lost follow-up after some consultations were excluded from the study. Therefore, data from patients who did not maintain outpatient follow-up were excluded from the study. Patient data were tabulated and evaluated after applying the inclusion and exclusion criteria. In some of these medical records, when data regarding visual acuity, renal function, smoking, weight, and height were not described, but the group considered that it would be possible to include the patient in the study due to the other parameters described, this patient was included in the analysis. We report, therefore, that some of this information is unknown in the results and tables.

Results

The reason for the initial care among the 500 patients who maintained outpatient follow-up was foot ulcer in 198 patients (39.6%), and the second reason was infection in 122 patients (24.4%). In 120 (24%), Charcot arthropathy in different stages was the cause for attendance, and 60 (12%) patients had diabetic neuropathy without other comorbidities in the foot. Three hundred and thirty-six patients were male (67.2%). The mean age was 65 years (ranging from 20 to 85 years), with almost 346 patients (70%) older than 50 years in initial care. Excess weight was a common characteristic, with a mean BMI of 26.11, noting that not all patients reported their weight (this information was available in 443 medical records). Most reported that they were non-smokers (81.4%; 407 patients) and non-alcoholics (85.2%; 426 patients). Type II diabetes predominated in the cases evaluated (94.4%; 472 patients). However, only 331 patients reported regular clinical visits (62.2%), and 18 did not know how often they visited the regular clinic to control diabetes (Table 1).

A minority of patients failed to comply with the recommendation for regular fundus examinations, leading to a lack of clinical data regarding their vision. In addition, a portion did not adhere to the laboratory tests indicated to evaluate renal function, while another portion neglected the vascular evaluation, resulting in a lack of information about these complications. Table 2 shows the data collected regarding visual acuity, renal function, and vascular disorders.

Amputations were performed in 306 (81.4%) patients at some point during outpatient follow-up, being classified as minor in 182 (59.5%) patients and major in 124 (40.5%). Eighty-seven patients (23.1%) were submitted to bone resections. In 34 (9%) patients it was performed some type of arthrodesis and isolated Achilles elongation, in 22 (5.9%) cases, 12 (54.5%) were open, and ten (45.5%) were percutaneous.

The anatomical and classifications of Eichenholtz are represented in Table 3. Charcot Arthropathy was observed in 126 (25.2%) patients.

Table 1. General characteristics of the 500 patients analyzed in the study

Category	Number of patients	Percentage (%)
Sex		
Male	336	67.2
Female	164	32.8
Age		
≥ 50 years	346	69.2
< 50 years	154	30.8
Body Mass Index		
Low weight (< 18.5)	2	0.4
Ideal (between 18.6 and 24.9)	133	26.6
Overweight (between 25.0 and 29.9)	182	36.4
Grade I obesity (between 30.0 and 34.9)	80	16.0
Grade II obesity (between 35.0 and 39.9)	35	7.0
Grade III obesity (over 40.0)	11	2.2
Did not reveal	57	11.4
Life habits		
Smokers	88	17.6
Non-smokers	407	81.4
Not informed	5	1.0
Alcoholic	66	13.2
Non-alcoholic	426	85.2
Not informed	8	1.6
Comorbidities and clinical control		
Diabetes type 1	28	5.6
Diabetes type 2	472	94.4
Insulin as treatment	307	61.4
Oral anti-diabetics	7	1.4
Regular clinical control	331	66.2
No regular follow-up	151	30.2
They were unable to answer	18	3.6

Table 2. Distribution of diabetes complications observed in the initial care

Category	Number of patients	Percentage (%)
Visual disorders		
Altered vision	219	43.8
Normal vision	253	50.6
Not informed	28	5.6
Kidney disorders		
Altered kidney function	76	15.2
Preserved kidney function	376	75.2
Not informed	48	9.6
Vascular disorders		
Vascular normality	234	46.8
Vascular disorders	248	49.6
Not informed	18	3.6
Ulcer		
With plantar ulcers	318	63.6
No plantar ulcers	182	36.4
Surgical indication		
Surgery performed	376	75.2
Surgery not indicated	124	24.8
Type of surgery*		
Amputations	306	81.4
Bone resections	87	23.1
Arthrodesis	34	9
Achilles stretch	22	5.9

Table 3. Eichenholtz anatomical and classification

Category	Number of patients	Percentage (%)
Anatomical classification		
Forefoot	13	10.3
Lisfranc	25	19.8
Chopart	8	6.4
Ankle and subtalar	42	33.3
Mixed involvement	33	26.2
The limit of involvement is not set	5	4
Eichenholtz classification		
Acute	9	7.1
Consolidation	28	22.2
Sequelae	78	62
Classification not defined	11	8.7

Discussion

It is believed that approximately 25% of patients diagnosed with diabetes will have foot complications related to neuropathy and vasculopathy[13,14]. Diabetic foot is one of the main causes of hospitalization in diabetic patients and is responsible for most amputations currently performed[2,13,15]. Knowledge of the profile of this diabetic patient who develops foot disorders is important to adjust an adequate prevention program, reduce hospitalizations and amputations, and reduce the cost to the health system[6,13,16]. In our study, we tried to trace the profile of patients seen at the foot outpatient clinic and found some interesting data.

In most patients in the study, the first visit was due to a foot ulcer (39.6%; 198 patients) or infection (24.4%; 122 patients). In 64% of patients, an already serious disorder was the reason for seeking specialized medical care. Both ulcers and infections are known factors that increase the risk of amputation, and these factors were of concern after our study's results. The focus of diabetic foot treatment should be the prevention of ulcers and infection[1,6,7]. Ideally, we should have more patients with insensitivity in the feet than patients with ulcers. Clarification campaigns on diabetic foot and prevention strategies should be conducted more strongly in our country[1,6,16]. Zhang et al.[2] drew attention to the fact that prevention is usually paid for by patients (specific shoes, socks, insoles, etc.) and the treatment by the health system, which could be unfavorable for wound prevention. A program in which the health system granted insoles and shoes to diabetic patients with neuropathy could reduce the number of complications and, consequently, the cost of treating them[8].

In our study, most patients (67.2%) were male. Evidence suggests an association between the male gender and a higher risk (up to 1.5) of developing foot complications[2,13,16]. One of the hypotheses for this association is the possibility of more daily physical activity among men[2].

We did not compare data from diabetic patients without foot disorders with those with diabetic foot, but in general, patients with diabetic foot tend to be older, have a longer diagnosis of diabetes, lower BMI, higher incidence of smoking, hypertension, and diabetic retinopathy[2,17]. The mean age in our study was 65 years, with almost 70% over 50 years in initial care. Zhang et al.[2] showed a mean age of 61.3 years for diabetic patients with foot ulcers, while those who do not have ulcers a mean age of 56.1 years. Pedras et al.[16] showed a mean age of 66 years. Although overweight was a common feature (mean BMI 26.11), we expected this number to be higher. Morbid obesity was not a common problem in our study group. Despite obesity being linked to the onset of diabetes, its contribution to the risk of diabetic foot ulcers still seems to be inconclusive[2]. Another fact that caught our attention was that more than 80% of patients declared not to be a smoker.

We expected a higher incidence of smoking. Smoking also interferes with peripheral microcirculation and, consequently, wound healing. As already described in the literature, diabetic smokers have a higher incidence of foot disorders[2,13,17]. As expected, type II diabetes predominated in our sample (94.4%). However, only 331 patients (62.2%) reported regular clinical control of the disease, and 18 patients did not know how often to visit the clinician to control diabetes (Table 1). Unfortunately, as we have found in certain cases, some patients are only diagnosed with diabetes after having a serious foot complication, which often leads to amputation immediately. Among the 1000 medical records evaluated, we only obtained data to perform this study in 500. Many patients submitted to minor/major amputation shortly after the initial care did not return to the outpatient clinic for follow-up. These patients were not included in our evaluation.

Charcot arthropathy is another serious complication of diabetic foot. Deformities resulting from this process of bone and capsulo-ligamentar destruction can lead to bony prominences, facilitating the appearance of ulcers[10-12]. Treatment in the early stages may decrease the number of severe sequelae of this condition. However, 62% of patients in the sample studied presented an already consolidated Charcot arthropathy in the sequelae phase. These patients have already arrived late to our outpatient clinic, and often, surgery was the only solution to the issue.

Among the 500 patients included in our sample, 306 patients (81.4%) were submitted to minor/major amputation due to infection, ulcers and/or deformity. This finding highlights the seriousness of the problem. It should be noted that, currently, the diabetic foot is the main factor for most amputations recorded[2,13,15]. We also observed that approximately 60% of the total amputations performed were classified as minor. It is worth noting that, whenever possible, it was decided to preserve the length of the lower limb to facilitate the ambulation of patients and promote an improvement in treatment adherence, glycemic control, and emotional well-being.

In our analysis of 500 patients submitted to diabetic foot treatment at the specialized outpatient clinic, a significant prevalence of patients who already had complications at the initial care was observed. Notably, most of these patients had skin ulcers or infections related to diabetic foot. Additionally, Charcot arthropathy in the sequelae phase was predominant among the patients evaluated. In the minority of our sample, only preventive measures were necessary, without direct intervention to treat established sequelae. Only 12% had exclusively diabetic neuropathy.

There are some limitations in our study. The retrospective design has bias. Half of the patients registered at the outpatient clinic were not evaluated (500 patients did not have sufficient follow-up or data in the medical record for inclusion in the study). This fact can completely change the evaluations of the study but also draw attention to the lack of adherence of the diabetic patient to the treatment. As mentioned above, many of the patients have already arrived at the clinic in need of amputation and sometimes did not even know they had diabetes. The trauma generated by hospitalization and emergency amputation often shocks the patient, who begins to deny the problem and does not return for follow-up. Another important point not evaluated in our study was the number of deaths. We did not have this information available for the entire sample evaluated and preferred not to include it.

The findings in our study are a warning about the need to direct efforts towards disseminating information and the implementation of prevention strategies to reduce the complications associated with diabetic foot.

Conclusions

Most patients followed at the diabetic foot outpatient clinic are men aged over 50 years, non-smokers and non-alcoholics, and with a slightly high body mass index of 26.1. They have already attended the outpatient clinic with foot complications and suffered some level of foot amputation.

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Original Article

Fourth generation minimally invasive osteotomy with rotational control for hallux valgus: a case series

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Abstract

Objective: Demonstrate the clinical and radiographic results of patients with hallux valgus (HV) treated by a fourth generation minimally invasive technique with rotational control of the first metatarsal.

Methods: Twenty-two patients were included in the study. All patients were women, with 14 right and eight left feet, with a mean follow-up of 15 months (12–18). The radiographic parameters evaluated were the hallux valgus angle (HVA), the intermetatarsal angle (IMA), the sesamoid displacement (Hardy Clapham), and the shape of the lateral edge of the first metatarsal head. The American Orthopaedic Foot and Ankle Score (AOFAS) score, visual analog scale (VAS), and complications were also evaluated.

Results: The HVA improved from the preoperative (26.8°) to the postoperative (4.2°) and the IMA from 13.2° to 2.7°. Regarding sesamoids, in the preoperative, three patients were grade 6, 10 were grade 5, and nine were grade 4. In the postoperative, ten patients were grade 2, and 12 were grade 1. In the preoperative, the lateral edge of the first metatarsal head was intermediate type in 18 patients and round type in four patients. In the postoperative, all patients were classified as angular type. The mean AOFAS increased from 45 to 91 points, and the mean VAS decreased from 6 to 1. The most common complication was surgical scar adherence in four patients.

Conclusion: The fourth generation minimally invasive technique with rotational control presented triplanar correction of the HV deformity. In addition, it provided pain improvement and functional gain with a low rate of complications.

Level of Evidence IV; Therapeutic Studies; Case Series.

Keywords: Hallux valgus; Bunion; Minimally invasive surgery; Percutaneous surgery; Triplanar osteotomy; Pronation.

Introduction

Hallux valgus (HV) has been treated as a biplanar deformity with the classic varus deviation of the first metatarsal and associated proximal phalanx valgus[1-3]. Over the years, with the intensification of studies and a better understanding of its physiopathology, it was understood that it is a complex triplanar deformity, also the first metatarsal pronation[2-4].

All components of the deformity must be addressed to achieve success in the surgical treatment, correcting the hallux valgus angle (HVA), the intermetatarsal angle (IMA), and the first metatarsal pronation[3-7]. There are open surgical techniques that directly address these components and achieve a three-dimensional correction[8-10]. Thus far, no percutaneous technique that adequately corrects the first metatarsal pronation has been validated.

Currently, percutaneous osteotomies to correct HV are divided into four generations[11]. In the fourth generation, osteotomy of the first metatarsal neck is transverse and addresses the rotational component indirectly[11]. The only percutaneous technique described in the literature that directly addresses rotational control through a specific guide was described by Nunes and Baumfeld[12]. To date, no case series in the literature evaluating the results of this technique has been published.

Study performed at the Clínica COTE Brasília, Brasília, DF, Brazil.

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The objective of this study is to demonstrate the clinical and radiographic results of patients with HV treated by a fourth generation minimally invasive technique with rotational control of the first metatarsal.

Methods

A case series including 22 patients diagnosed with moderate to severe HV submitted to fourth generation minimally invasive osteotomy with direct rotational control. All patients were submitted to surgery by surgeons specialized in foot and ankle and minimally invasive technique in two tertiary centers from January 2021 to June 2022. The study was approved by the institutional review board and all patients signed the informed consent form and agreed to be included in the study.

Inclusion criteria were patients diagnosed with moderate to severe HV (HVA > 20 and IMA > 11)[13], sesamoid displacement grade ≥ 4 according to Hardy and Clapham classification[14], and intermediate or round shape of the lateral edge of the first metatarsal head as described by Okuda et al.[15]. Exclusion criteria were arthrosis of the hallux metatarsophalangeal joint, rheumatological, neurological and vascular disorders, patients who failed to follow the postoperative protocol or who missed a minimum follow-up of 12 months.

All patients were evaluated clinically and radiographically in the pre-and postoperative, with a mean follow-up of 15 months (12–18). Clinical evaluation included the American Orthopaedic Foot and Ankle Score (AOFAS)[16] for the forefoot and the visual analog pain scale (VAS)[17]. All complications were documented. Radiographic evaluation was obtained in the anteroposterior (AP) and lateral views with weight-bearing. The HVA, IMA, sesamoid displacement, and the shape of the lateral edge of the first metatarsal head were evaluated. The sesamoid position was evaluated according to the tibial sesamoid position described by Hardy and Clapham[14]. Pronation was evaluated according to the classification of Okuda et al.[15]. This classification is based on the lateral edge of the first metatarsal head on AP radiographs with weight-bearing. The lateral edge of the first metatarsal head can be classified as angular (type A), intermediate (type I), or round (type R). Type A corresponds to no or mild pronation up to 20°[15]. Type I corresponds to moderate pronation between 20° and 30°, and type R corresponds to pronation of 30° or over[15]. Two orthopedic foot and ankle surgeons trained and not involved in the surgical procedure performed radiographic evaluation.

Surgical technique

The surgical procedure was performed according to the description of Nunes and Baumfeld [12].

The equipment used was: Beaver blade, Shannon cutter 2×10 mm; Wedge cutter 3.1; High torque and low rotation motor, C-arc fluoroscopy, cannulated screws, and a specific guide for rotational control.

The patient was submitted to spinal anesthesia and sedation and was positioned in the supine position with the feet hanging freely at the end of the table and supported by fluoroscopy.

Pin introduction in the rotational guide

The rotational guide was positioned on the first metatarsal to ensure the proximal component stays under the medial cuneiform and the distal component under the first metatarsal head. Through the rotational guide, pins were inserted into the medial cuneiform and metatarsal head. In the medial cuneiform, the pin must be inserted at the 0º mark. The distal pin was inserted into the first metatarsal head through the rotational guide to be corrected, according to preoperative planning (correction of 10°, 20°, or 30° was possible) (Figure 1).

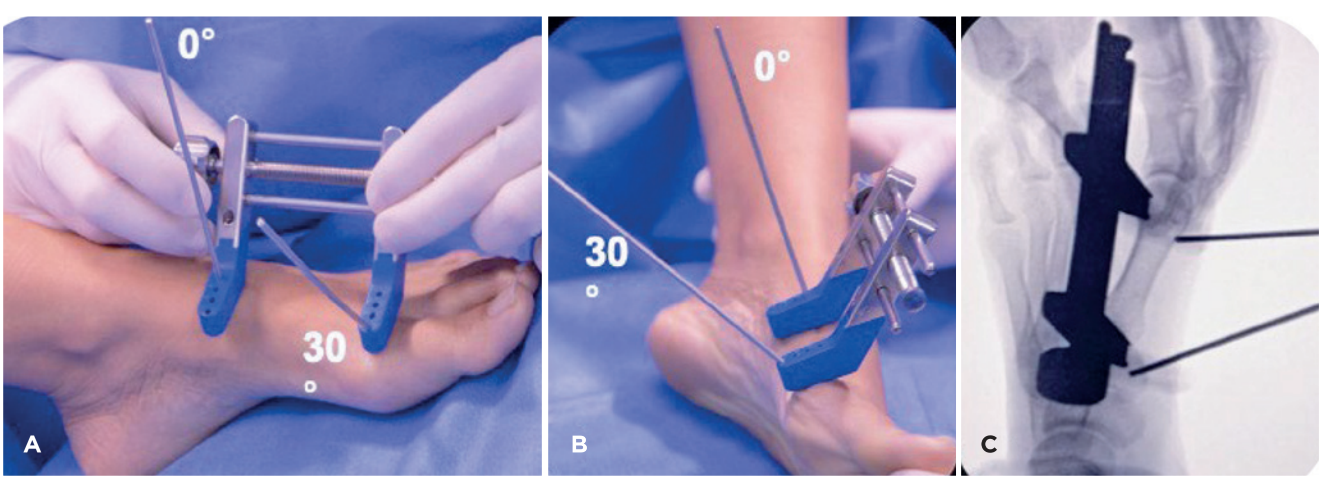

Figure 1. Introduction of rotational pins.

For patients classified type I lateral edge of the first metatarsal head, a correction of 20° was performed, and for type R, a correction of 30°. After the insertion of the pins, the guide was removed.

First metatarsal osteotomy

Through an extracapsular portal, the distal metaphysis-diaphyseal transition of the first metatarsal was established using a beaver blade. Then, a transverse osteotomy was performed using a Shanon cutter 2 x 10 mm (Figure 2).

Reducing and fixation maneuver

The next step was to place two guide wires for 4.0 mm cannulated screws only on the proximal fragment, leaving the metatarsal head free (Figure 3). After introducing the guide wire into the proximal fragment, it proceeded to the reduction maneuver. The first step of reduction is the lateral displacement of the first metatarsal head, which is performed by introducing a blunt instrument into the medullary canal of the first metatarsal (Figure 4).

The second step of reduction was rotational correction. The proximal and distal rotational pins must be fitted back into the rotational guide at the 0° mark. For this to occur, the distal rotational pin previously inserted in the metatarsal head in the rotation to be corrected must be rotated until it reaches the 0° mark in the rotational guide (Figure 5). After the rotational correction of the previously inserted guide wires, only proximal osteotomy fragments were advanced by fixing the distal fragment (Figure 6). The fixation was completed with the introduction of two 4.0 mm cannulated screws (Figure 7). After fixing, the rotational guide and its pins were removed. Through the distal screw portal, the medial diaphyseal prominence was removed with the Shannon cutter 2 x 10 mm (Figure 8).

Akin osteotomy

Akin osteotomy was performed by a mid-axial portal on the medial edge of the proximal phalanx with the Shannon cutter 2 x 10 mm. Then, bone debris removal was performed with abundant saline irrigation. The procedure was completed by closing the surgical incisions and applying a padded dressing and adhesive tape (Figure 9).

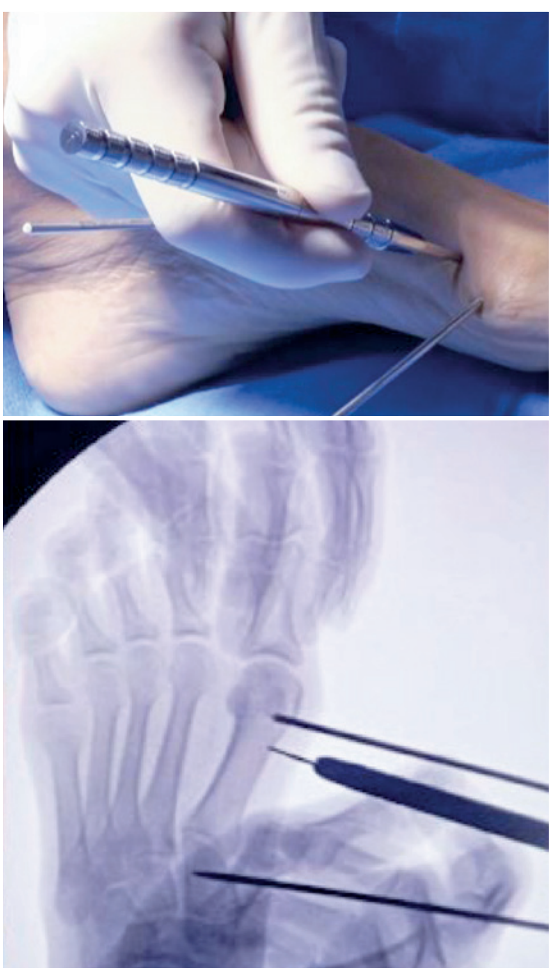

Figure 2. Beaver incision for transverse extracapsular osteotomy.

Figure 3. Positioning of guide wires.

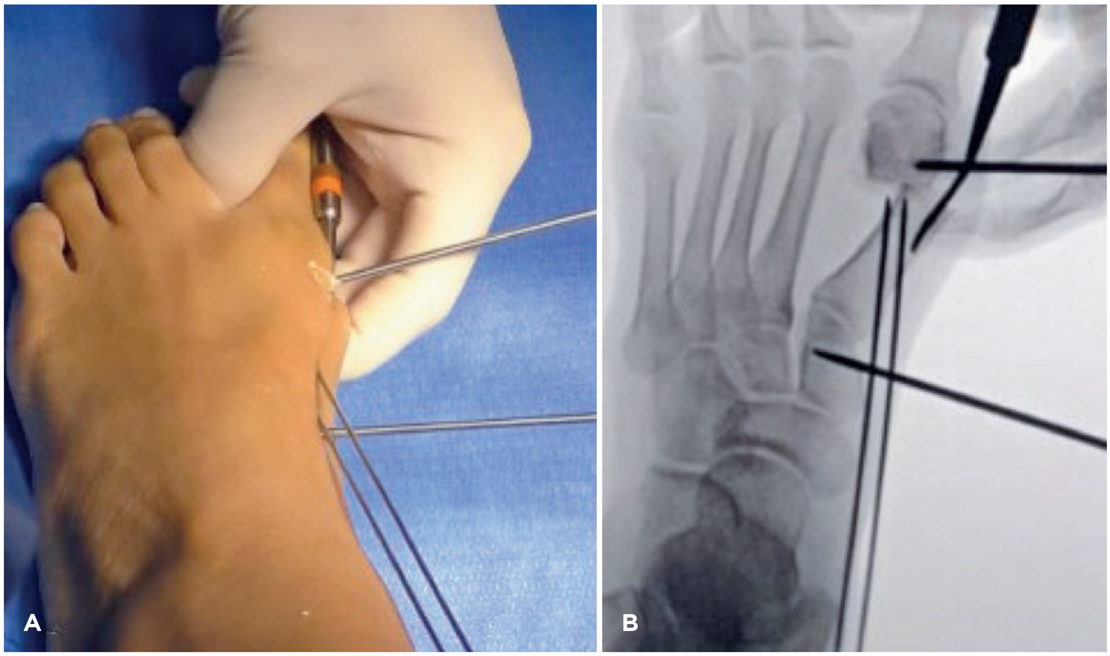

Figure 4. Lateral displacement of the metatarsal head.

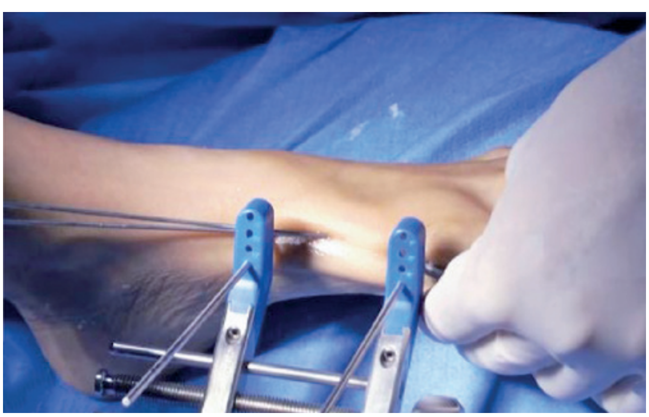

Figure 5. Rotational correction.

Postoperative protocol

1. Partial support using orthopedic sandals with rigid soles and crutches for six weeks.
2. After the first week, the surgical dressing is replaced with band-aids applied to the portals.
3. Active and passive exercises for the hallux range of motion started in the first week and intensified in the follow-up according to the evolution of the patient.
4. After the sixth week, patients could wear conventional shoes with a wide anterior chamber and rigid soles.
5. Radiographic control was performed at 2, 6, and 12 weeks, and 6 and 12 months.

Figure 6. Advance of guide wires to distal fragment.

Statistical Analysis

The SPSS 26 (2019), Minitab 21.2 (2022), and Microsoft Excel 2010 for statistical analysis were used. All variables followed a normal distribution, tested by the Shapiro-Wilks

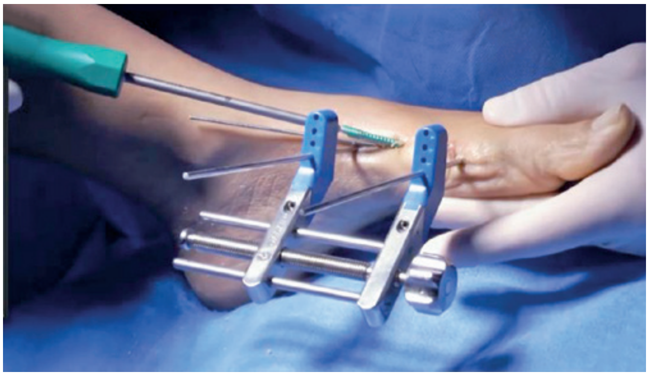

Figure 7. Fixation with two 4.0 mm canullated screws.

Figure 8. Removal of the medial diaphyseal prominence.

test[18]. Student t-test[19] was applied to compare the variables. Variables with a p-value < 0.05 were considered statistically significant.

Figure 9. Pre-and postoperative correction by the fourth generation minimally invasive osteotomy technique with rotational control.

Results

The 22 patients were female, and the mean age was 44 (33–60). Fourteen surgeries were performed on the right foot and eight on the left, with a mean follow-up of 15 months (12-18).

The comparison of the pre-and postoperative radiological variables is shown in Table 1. There was a statistical difference between the pre-and postoperative values of HVA and IMA. Regarding sesamoids, in the preoperative, three patients had grade 6, ten grade 5, and nine grade 4. In the postoperative, ten patients had grade 2 and 12 grade 1. In the preoperative, the lateral edge of the first metatarsal head was type I in 18 patients and type R in four patients. In the postoperative, all patients were classified as type A.

Table 2 shows the pre-and postoperative comparison of clinical variables. There was a statistical difference between the pre-and postoperative values of AOFAS in the forefoot and VAS.

The most common complication was scar adherence, present in four patients. In addition, two other patients reported discomfort with the synthesis material, which needed removal. No cases of infection, pseudoarthrosis, recurrence, or fracture of the medial cortical of the proximal fragment were identified.

Table 1. Pre-and postoperative radiological variables

Variables	Preoperative (mean)	Postoperative (mean)	p-value
HVA	26.8°	4.6°	0.0054*
IMA	13.2°	2.7°	0.0043*

HVA: Hallux Valgus angle; IMA: Intermetatarsal angle
*Statistically significant

Table 2. Mean AOFAS and VAS in the pre-and postoperative

Variables	Preoperative (mean)	Postoperative (mean)	p-value
AOFAS	45	91.1	0.0014*
VAS	6	1	0.0027*

[AOFAS: American Orthopaedic Foot and Ankle Score; VAS: Visual Analog Pain Scale
*Statistically significant.

Discussion

First metatarsal pronation is present in 87% of patients with HV. The importance of its correction is associated with a decrease in the recurrence rate(3,5,20). There are several ways to evaluate first metatarsal pronation. The best method described in the literature is computed tomography with weight-bearing through the alpha angle(3,21). Despite being an efficient method, it is not available in all medical centers. Radiography is a more available method that indirectly demonstrates the first metatarsal rotation through the sesamoid position(14,22) and the lateral edge of the first metatarsal head(15).

Radiographic evaluation of first metatarsal pronation is still a controversial method and topic of discussion. Some authors studied the lateral edge of the first metatarsal head and described it as a reliable radiographic method to evaluate the internal first metatarsal rotation(5,15,23). This indirect radiographic evaluation provides approximate values and should be used only in patients without signs of arthrosis of the hallux since osteophytes may impair the evaluation of the lateral edge of the first metatarsal head(4). Given this, our study used the lateral edge of the first metatarsal head to calculate the rotation to be corrected and excluded patients over 60 years and those with signs of arthrosis of the hallux metatarsophalangeal or gleno-sesamoid joint. Another indirect radiographic way that can be used to evaluate rotation correction is sesamoid reduction. A strong relationship between high values of first metatarsal pronation with sesamoid classified Hardy Clapham grades 4 and 7 was demonstrated(24).

Some authors have described a technical tip for correcting the first metatarsal rotation using a Kirschner wire attached to the first metatarsal head, using the sesamoid position as a reference(25). Although it is a good alternative when we do not have a rotational control guide available, it is a subjective technique, as it depends on the surgeon's experience and is based on a fluoroscopic intraoperative image without foot weight-bearing. In addition, the foot's position during fluoroscopy can significantly influence the sesamoid position(1,26,27). In our study, the rotation to be corrected was evaluated preoperatively, and the rotation correction was controlled intraoperatively through a specific guide. We believe this makes this method more reliable and reproducible, as in the last follow-up of this study, all patients had sesamoid displacement classified as Hardy and Clapham between grade 2 and 1, and the lateral edge of the first metatarsal head grade 0 and 1

The power of correction by percutaneous techniques has already been well established. In a recent case series, 60 patients corrected using the minimally invasive Chevron Akin (MICA) technique were evaluated, which was able to correct the HVA from 41.2° to 11.6°, while the IMA reduced from 17.1° to 6.9°(28). Another study with a follow-up of two years showed a reduction of HVA from 30.4° to 10.2°(29). In our study, the correction power was similar, with a reduction of HVA from 26.8° to 4.6º, while the IMA from 13.2° to 2.7°.

An advantage of minimally invasive surgery is the early improvement of pain. Lee et al. conducted a randomized prospective study of 50 patients comparing the clinical and radiographic outcomes of surgical treatment of HV with percutaneous Chevron osteotomy with conventional open osteotomy(30). The result showed that pain during the acute postoperative phase was statistically lower in the subgroup treated with percutaneous surgery (30). In addition, Keppler et al. demonstrated a great improvement in VAS from 8.2 to 1.2 at the follow-up of two years in patients treated with the MICA technique(31). In our study, the findings were similar, with a final mean VAS of only 1 point.

Regarding clinical criteria, several studies reported significant improvement in patients' function(32,33). Nunes et al. reported preoperative AOFAS of 42.8 and 90 in the postoperative, and Jowett and Bedi obtained an improvement in AOFAS from 56 to 87 points in the postoperative of 106 patients(28,34). Our series showed a similar improvement, with preoperative and postoperative AOFAS of 45 and 91.1, respectively.

Our study had some minor complications. In four cases (19%) scar adherence was observed in the medial access of the first metatarsal neck. We believe this occurred because this region has little subcutaneous tissue, and the surgical wound mobilization was not performed properly in the postoperative. There were only two cases (9%) with discomfort in the synthesis material needing removal. Other studies show higher incidences of this type of complication, with rates of up to 16%(28).

This study has several limitations. There was a short follow-up time that may be not sufficient to evaluate some complications, especially the recurrence. A greater number of participants with a control group would increase the reliability of the result. The first metatarsal rotation was evaluated by a radiographic method that provides approximate values. The ideal would be the use of computed tomography with weight-bearing. Despite these limitations, this is the first case series in the literature to describe a case series of percutaneous technique that directly addresses the rotation correction of the first metatarsal by evaluating the sesamoid position and the lateral edge of the first metatarsal head.

Conclusion

The fourth generation minimally invasive technique with rotational control used in this study to correct HV deformities presented pain improvement and functional gain with a low rate of complications. In addition, it could perform a three-dimensional correction of the deformity.

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Case Report

Use of Figueiredo's technique for treating extensive infected skin lesions – a case report

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Abstract

Demonstrate that a low-complexity surgical technique can effectively solve problems of extensive skin lesions in cities where microsurgical techniques are not available. We present a 59-year-old male patient with diabetes mellitus and an extensive and infected lesion in his right ankle region, suggestive of a diabetic foot. Urgent surgical treatment was performed with debridement of the devitalized tissues, drainage of a large amount of purulent secretion, and exhaustive washing with 0.9% saline solution. After a new debridement, abundant washing with 0.9% saline solution and coverage of the extensive bloody area with a polypropylene prosthesis were performed. He remained under outpatient follow-up, and subsequently, twice, new cleanings were performed, and a small diameter mesh was applied due to the good evolution of healing. A good range of motion was maintained in the right ankle and foot, with the medial wound completely healed, leaving only a small area of the lateral wound to complete the healing process. Figueiredo's technique, described in 2017 for fingertip lesions, uses a flexible thermoplastic polymer, which can be obtained from a small portion of silicone from a saline bag, to form a semi-occlusive dressing that allows the drainage of secretions and provides a favorable environment and temperature for healing. The exact limits of this technique are not yet well established, but the practice has shown excellent results in larger lesions. Figueiredo's technique is a simple, low-cost, and effective option for treating extensive infected skin lesions.

Level of Evidence IV; Therapeutic studies; Case Report.

Keywords: Skin lesion, Polypropylene; Wound healing.

Introduction

Extensive skin loss has always been a challenge for surgeons. Microsurgical skin flaps are considered the most appropriate procedure for resolving this type of lesion, but they are technically dependent on microsurgeons with specialized training and high-cost specific material, including microscopes that are not always available[1,2].

Furthermore, they require a donor area of skin tissue, generally coming from a non-injured area of the patient, and a surgical procedure in a non-injured donor area could cause some consequences for that area[3].

In an attempt to find a solution without these difficulties, using the regenerative capacity of our own body and intervening only in the injured area, in 2017, Figueiredo LA described a technique for covering lesions with a polypropylene prosthesis, allowing the body to perform its healing by secondary intention, in a protected manner and without the need to use an intact donor area for grafts and flaps[1].

Some techniques using the protection of synthetic materials to obtain secondary healing, especially in small open areas such as the fingertip or nail region, have already been described, all with advantages and disadvantages[4,5].

Study performed at the Hospital Português de Beneficência em Pernambuco, Recife, PE, Brazil.

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In Figueiredo's technique, the prosthesis is low-cost, easy to obtain at any medical service, and translucent, allowing for better monitoring of the case's evolution[1,2]. An important advantage that we must consider about this technique is the low cost, as it uses widely available and cheap materials, does not require high-cost microsurgical therapies, has a relatively quick hospitalization time, and reduces intravenous antibiotic therapy compared to other procedures[1].

The exact limits of this technique are not yet well established, but the practice has demonstrated excellent results in larger lesions[2].

Therefore, we consider it important to describe the case of an extensive infected skin lesion successfully treated using Figueiredo's technique.

Case report

We present a 59-year-old male patient with diabetes mellitus and an extensive and infected lesion on the lateral and medial regions of his right ankle, suggestive of a diabetic foot, on December 27, 2021. Urgent surgical treatment was performed with debridement of the devitalized tissues, drainage of a large amount of purulent secretion, and exhaustive washing with 0.9% saline solution, resulting in open areas with a small secretion (Figure 1). On January 09, 2022, a new debridement was performed + abundant washing with 0.9% saline solution. The extensive bloody areas of the right ankle were also covered with protective mesh-a polypropylene prosthesis (Figures 2 and 3). After hospital discharge, the patient was instructed to change the dressing weekly, taking care not to damage the protective mesh. He remained under outpatient follow-up, and on Abril 02, 2022, it was decided to perform a new surgical cleaning and application of mesh with a smaller diameter due to the good healing progress. The patient attended the service weekly for dressing changes until March 04, 2022, when he was submitted to a new surgical procedure to replace a new polypropylene prosthesis in dimensions more appropriate to the diameter of the remaining area. The wound was treated only with cleaning surgery + Figueiredo's technique. During the healing process, there was no secretion, worsening of the clinical condition, or need for antibiotics. Cephalexin was used only seven days after each change of the protective mesh. The physical examination revealed a considerable healing process and good perfusion in the affected limb. The patient began receiving home care from the "Melhor em Casa" program with a multidisciplinary team to change dressings and monitor the lesion. He maintains a good range of motion in his right ankle and foot, with the medial wound completely healed, with only a small area of the lateral wound remaining to complete the healing process. He is currently awaiting further feedback to define the final course of action regarding the lateral area (Figure 4).

Discussion

Figueiredo's technique, described in 2017 for fingertip lesions, uses a flexible thermoplastic polymer, which can be obtained from a small portion of silicone from the saline bag, to form a semi-occlusive dressing that allows drainage of secretions and provides an environment and temperature favorable to healing. In short, the principle of Figueiredo's

Figure 1. Initial appearance of the medial and lateral bloody areas.

Figure 2. Cover of the lateral area with polypropylene protection.

Figure 3. Cover of the medial area with polypropylene protection.

Figure 4. Current appearance of the lesion.

Technique for treating skin loss is the inorganic protection of the wound with polypropylene while the body itself carries out its healing process by secondary intention[1].

The aesthetic results of Figueiredo's technique demonstrate a better appearance than other techniques, which can be attributed to the fact that it preserves the characteristics of the lesion site. In contrast, other methods transfer the characteristics of the donor area to the recipient area, changing the appearance and aesthetic of both[1].

The wound was treated only with cleaning surgery + Figueiredo's technique. During the healing process, there was no secretion, worsening of the clinical condition, or need for antibiotics. This seems to confirm previous work on the technique, which states that the exudate provides an environment that favors healing without infection[1,2].

Secondary healing did not create any type of adhesion over the tendons, and the patient presented results with complete mobilization of the ankle and toes, as already demonstrated in other studies[1,2].

The exact limits of this technique are not yet well established, but the practice has demonstrated excellent results in larger lesions, especially the distal leg, foot, and calcaneus[2].

For these reasons, we decided to use this method on an extensive infected ankle skin lesion in a diabetic patient, a case that many would consider too complex to apply Figueiredo's technique. However, the patient lived in a location without access to microsurgical techniques and did not have the resources to seek a larger health center.

The results were surprising, with a quick and painless evolution to complete closure of the medial wound and, at the time this study was written, almost complete closure of the lateral area, maintaining normal range of motion in the ankle and resolution of the infectious process.

The use of Figueiredo's technique is a simple and effective option for treating extensive infected skin lesions.

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Technical Tips

Anterior and posterior ankle arthroscopy in prone position: description of surgical technique

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Abstract

Ankle arthroscopy has several advantages compared to open surgery and can be performed anteriorly or posteriorly. Pathologies located in the anterior and posterior ankle regions may coexist and require combining the abovementioned arthroscopic techniques. The objective of this study was to describe the anterior and posterior ankle arthroscopic technique for treating lateral instability and posterior ankle impact, keeping the patient in prone position. The arthroscopic technique described with the patient in prone position allowed access to the anterior and posterior regions of the ankle, allowing the treatment of lateral ankle instability and posterior impact, potentially reducing the risks present in the change of decubitus position during surgery.

Level of Evidence V; Therapeutic Studies; Expert Opinion.

Keywords: Ankle joint; Arthroscopy; Joint instability; Ligaments; Prone position.

Introduction

Ankle arthroscopy has several advantages compared to open surgery, with less soft tissue trauma and an earlier return to daily and sports activities. It is also an important diagnostic technique for several ankle pathologies[1-4]. Indications for anterior ankle arthroscopy include ankle impingement, osteochondral injuries, and ankle instability. The posterior ankle arthroscopy described by van Dijk covers other indications, such as the posterior ankle impact, flexor hallucis longus tenosynovitis, and subtalar coalitions[2,5]. Pathologies located in the anterior and posterior ankle regions may coexist and require combining the abovementioned techniques, especially in treating anterior and posterior impingement syndrome[6-11].

D'Hooghe et al.[12] demonstrated that athletes diagnosed with chronic lateral ankle instability are ten times more likely to require surgery to treat the posterior impact by os trigonum than athletes with acute lateral ankle ligament injuries. In contrast, Strauss et al.[13] demonstrated that lateral ankle sprains could aggravate the posterior impact caused by os trigonum and become a cause of chronic pain.

Good functional results with arthroscopic treatment for lateral instability and posterior impact, associated with a low incidence of complications, have been reported in the literature[6-11, 14-19]. The combination of anterior and posterior in prone position also obtained good results, and no complications were obtained for impact treatment[10]. However, no studies describe the association of techniques in treating lateral instability and posterior impact with the patient kept in prone position.

The objective of this study is to describe the anterior and posterior ankle arthroscopic technique for treating lateral instability and posterior ankle impact, keeping the patient in prone position. This surgical strategy would reduce the risks of contamination of instruments and surgical fields and reduce the operative time, increased by changing the decubitus position. In addition, it would potentially facilitate the operative strategy in cases that require multiple changes in anterior and posterior accesses.

Study performed at the Universidade Federal de São Paulo - Escola Paulista de Medicina, São Paulo, SP, Brazil.

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The technique description – preoperative evaluation

This study was approved by the Institutional Review Board, and the patient signed the informed consent form. This study was conducted in accordance with the Declaration of Helsinki and the Health Insurance Portability and Accountability Act (HIPAA).

An 18-year-old male patient without comorbidities, with a history of recurrent sprains and pain in the lateral and posterior region of the right ankle, exacerbated by forced flexion, was selected for the study. The complaints began 12 months prior, after the first episode of ankle sprain, and in that period, the patient was submitted to conservative treatment with physiotherapy and orthosis without improvement. The physical examination showed pain on palpation of the anterolateral gutter, positive anterior drawer test, and pain at the end of ankle flexion, which was reported in the posterior ankle region. It had no deformities on inspection. He was also submitted to radiographs and magnetic resonance imaging, showing damage to the anterior talofibular ligament and os trigonum syndrome associated with spinal cord and fluid bone edema in the posterior tibiotalar and talocalcaneal recesses. Clinical and imaging findings corroborated the diagnosis of chronic lateral instability and posterior ankle impingement (Figures 1–3).

The American Orthopedic Foot and Ankle Society (AOFAS) hindfoot score and the visual analog pain (VAS) scale were collected during the preoperative evaluation, resulting in 67 and 7.2, respectively.

Surgical technique

After sedation, the patient was positioned in prone position with a peripheral block (popliteal and saphenous), and a thigh pneumatic tourniquet was applied (Figure 4).

The surgery started through the posterior access, initially through the posterolateral portals, followed by the postero-medial portal[20]. The neurovascular bundle was avoided at this stage through lateral access to the flexor hallucis longus tendon. Synovectomy and capsulotomy of the subtalar joint were performed using a shaver blade, allowing the visualization of the posterior talus region. From that moment on, os trigonum was identified, and its resection began. Using a shaver and Basket forceps, the os trigonum was detached from the talus and partially resected to have its size reduced,

Figure 1. Presence of os trigonums on ankle radiograph in profile position.

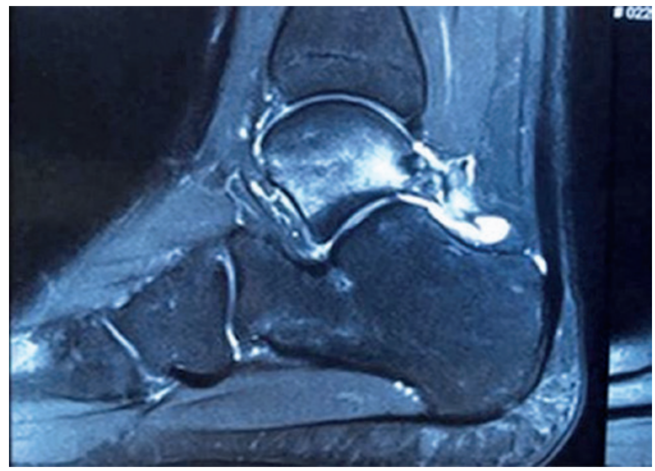

Figure 2. Ankle magnetic resonance imaging in sagittal position showing the *os trigonum* associated with spinal cord and fluid bone edema.

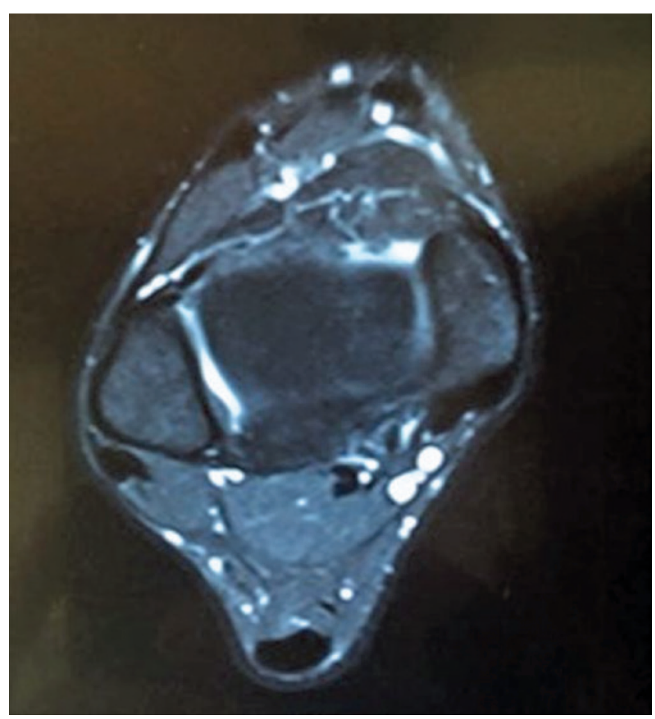

Figure 3. Ankle magnetic resonance imaging in axial position showing the lateral ligament injury.

thus enabling the introduction of Kocher forceps for the total removal of the accessory bone (Figure 5).

Still in prone position, the anterior ankle region was accessed through knee flexion at 90º, which the second assistant maintained in this position. The anteromedial portals were made, performed medial to the anterior tibial tendon, avoiding the saphenous nerve and the great saphenous vein, followed by the anterolateral portal, performed medial to the superficial fibular nerve to prevent injury, making it possible to visualize the structures such as the anterior arthroscopy performed in dorsal decubitus, but with the upside-down images resulting from the limb position, needing to adapt the conventional intraoperative maneuvers. At this time, synovectomy and lateral gutter debridement were performed to expose the region where the ligaments originate in the fibula. Then, through the anterolateral portal, a 3.0 mm anchor was introduced 1 cm from the lateral malleolus apex using guidewires. The anchor wires were then passed through the safety zone through the lower extensor retinaculum, as described in the arthroscopic Bröstrom-Gould technique[16,17], and sutures were performed with the ankle in eversion, allowing lateral ligament reconstruction without the need for decubitus change and the exchange of operative fields (Figure 6).

Figure 4. Patient positioned in prone position and anterior and posterior portals marked.

Postoperative period

The patient was instructed to maintain no weight-bearing in the first postoperative week; from the second to the fourth week, progressive partial weight-bearing was initiated with crutches and an immobilizer; from the fifth to the eighth week, a rigid anklet was allowed, then was progressively removed until the end of the sixteenth week.

Rehabilitation with physiotherapy began in the second week, allowing isometric strengthening, gain of ankle extension and eversion, and flexion of up to 20º. Inversion and internal

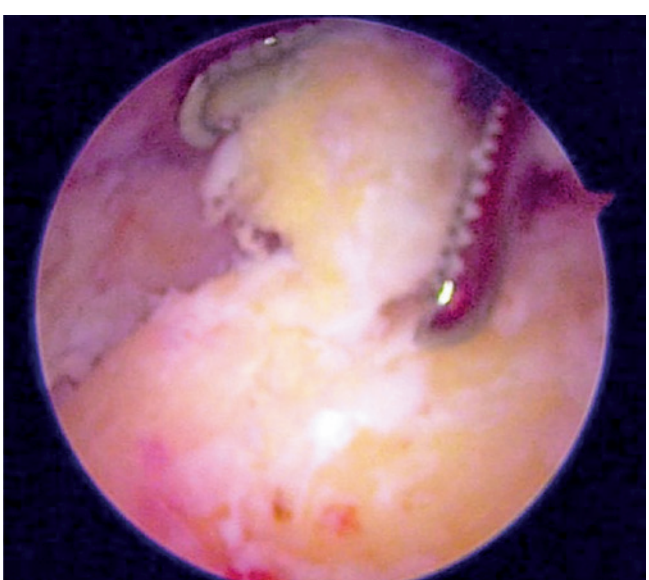

Figure 5. Arthroscopic identification of the os trigonum and its removal with forceps.

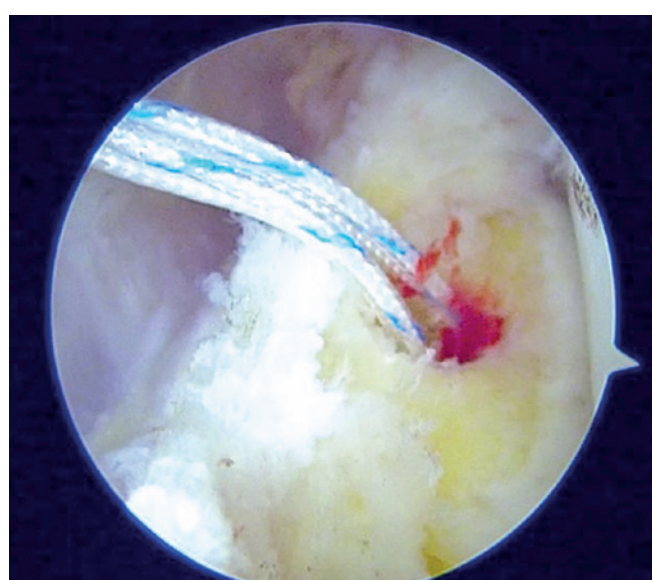

Figure 6. Intraoperative image demonstrating fibula visualization and anchor positioning for lateral ligament reconstruction.

rotation movements were restricted until the sixth week. The sutures were removed in the third week, and no problems with the operative wounds were observed. Light physical activities were released in the sixth week, and the intensity was allowed to increase from the eighth week.

In the twelfth week postoperatively, the patient was already gradually returning to previous physical activities, and the AOFAS and VAS scores were again collected, resulting in 94 and 0, respectively. Comparing the scores and preoperative complaints, the patient showed significant improvement and satisfactory results with the surgery. There were no complications related to the procedure.

Discussion

The arthroscopic techniques described in the literature for treating lateral ankle instability[14,16-19] and those directed to the posterior ankle impact [5-11,15] present good functional results and low incidence of complications. Our study aligns with the literature since the reported patient showed improvement in pain and functional scores after surgery, allowing the return to sport in the expected three months without complications associated with surgery.

Distraction during arthroscopy can improve the visualization of a congruent joint such as the ankle [21]. However, complications are associated with this method, such as neurovascular compression and skin necrosis[22]. In the technique described, clear images were obtained without the need to apply traction to the limb, avoiding these events.

This study has some limitations. The procedure described imposes greater technical difficulties, requiring an experienced team in arthroscopic procedures. Also, it presents a difficulty in understanding the images, which can be confusing to interpret at first, and the need to adapt the surgical technique of the anterior access with the knee kept flexed. The sample presented was small and without a control group to compare. Other comparative studies are needed to evaluate the reduction in surgical time and the lower risk of contamination of the instruments in the change of decubitus position. In addition, studies with a larger number of patients submitted to the technique and a longer follow-up are necessary to evaluate functional results better.

The arthroscopic technique described with the patient in prone position allowed access to the anterior and posterior regions of the ankle, allowing the treatment of lateral ankle instability and posterior impact, potentially reducing the risks present in the change of decubitus position during surgery.

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