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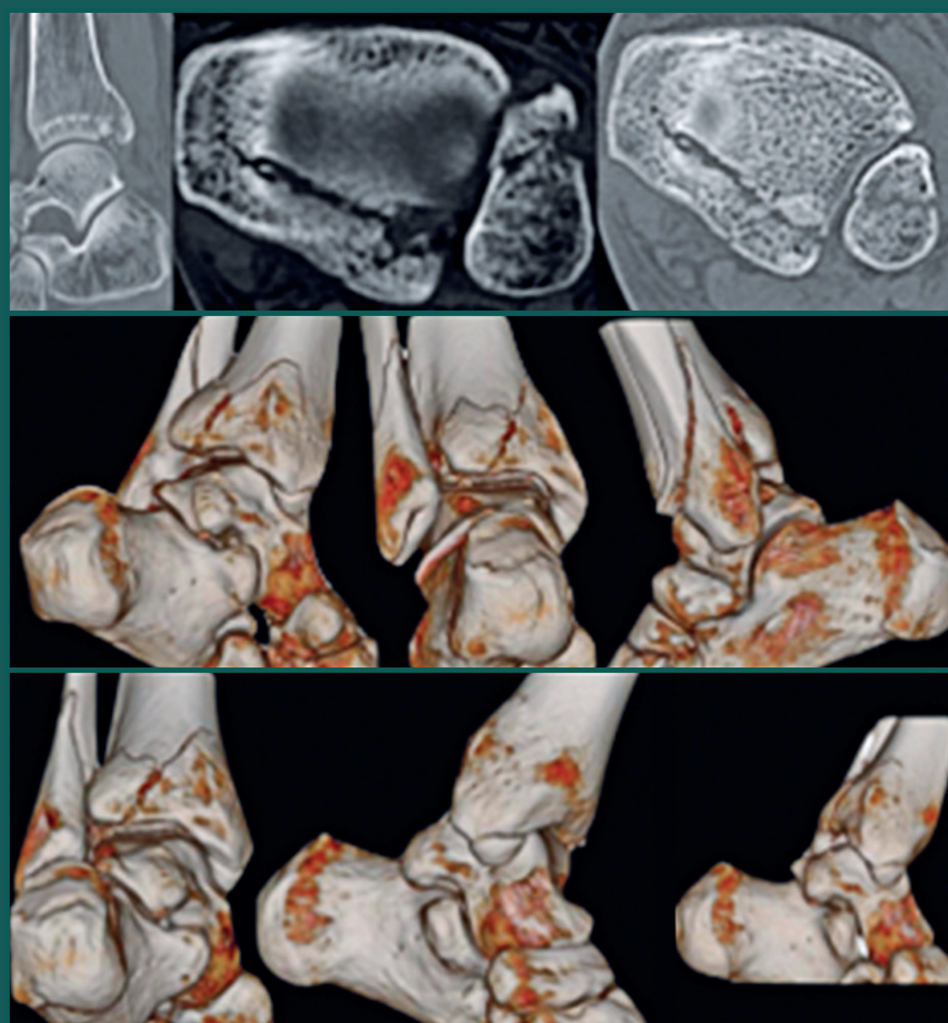

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From regional roots to global reach: Twenty years of the Journal of the Foot and Ankle

CAIO NERY, M.D.
ESCOLA PAULISTA DE MEDICINA
HOSPITAL ISRAELITA ALBERT EINSTEIN

It is with great pride and satisfaction that we present the first issue of Volume 20 of the *Journal of the Foot and Ankle*. This milestone represents far more than the passage of time – it reflects a journey defined by purpose, resilience, and an enduring commitment to scientific excellence.

Over the past two decades, this journey has been shaped by passion, dedication, and collaboration. It has included challenges – some overcome, others not – but always guided by a shared mission: to stimulate, disseminate, and advance high-quality scientific knowledge in Foot and Ankle Medicine and Surgery.

To fully appreciate the significance of this moment, it is important to revisit our origins.

The foundation of this journey lies in two parallel initiatives that emerged almost simultaneously in Latin America. In Brazil, Dr. Antonio Egydio de Carvalho Jr. established the *Revista da ABTPé*, while in Argentina, Dr. Alberto Maklin Vadell founded *Tobillo y Pie*. Both journals played a pioneering role in fostering regional scientific production, despite facing the well-known political and economic challenges inherent to the Latin American context. Competing for the same authors, reviewers, and readership, each contributed—independently yet meaningfully – to the development of our specialty.

During their first decade, these journals collectively published nearly 400 articles. However, this divided editorial effort limited their ability to reach the critical mass required for international indexation. It became increasingly evident that a structural transformation was necessary.

A major step forward was achieved under the leadership of Dr. Jorge Mitsuo Mizusaki (Editor-in-Chief, 2016–2019), who restructured the Brazilian journal, renaming it the *Scientific Journal of the Foot and Ankle* and transitioning its publication language to English. This strategic evolution significantly increased annual scientific output. Nevertheless, even with this progress, the requirements for indexation remained just beyond reach.

The need for unity became clear.

The consolidation of these efforts into a single, stronger scientific platform emerged as the natural path forward – one capable of representing Latin American research with greater visibility and impact. After extensive and thoughtful discussions, this vision materialized in 2019 with the creation of the *Journal of the Foot and Ankle (JFA)*. More than a merger, it represented the convergence of histories, experiences, and shared aspirations, preserving the editorial legacy of both journals while establishing a new and ambitious direction.

It would be impossible to acknowledge individually all those who contributed to this transformation. Colleagues from across Latin America played essential roles in shaping the discussions and decisions that led to the creation of JFA. Their collective effort made it possible to build a journal that now stands as a credible and competitive platform for high-quality scientific publication – not only within Latin America, but increasingly on the global stage.

The appointment of Dr. Alexandre Leme Godoy-Santos as the first Editor-in-Chief marked the beginning of a new phase, defined by clear strategic goals. Chief among them was achieving the standards required for indexation in major international databases – an objective pursued with consistency, discipline, and long-term vision.

By bringing together the scientific contributions of Latin America with those of Portugal and Spain, the journal has now reached the benchmarks required by SciELO, achieving an annual publication volume aligned with international standards. With this, the path toward indexation is no longer a distant aspiration but a tangible and imminent reality.

This is what we celebrate today: not only twenty years of history, but the strength of a collective vision, the perseverance of a scientific community, and the transformation of regional roots into a platform with global reach.

The future is no longer ahead of us – it has already begun.

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Special Article

Clubfoot: an updated review

Alexandre Francisco de Lourenço[1]

1. Escola Paulista de Medicina, Universidade Federal de São Paulo, São Paulo, SP, Brazil.

Abstract

Congenital talipes equinovarus, commonly referred to as clubfoot, is one of the most frequent congenital deformities of the lower limb. Over the last few decades, a major paradigm shift has occurred in its management, with the Ponseti method becoming the gold standard for treatment worldwide. However, other treatment modalities, including selected surgical procedures, may still be required. This review aims to provide an updated overview of the epidemiology, etiology, pathoanatomy, clinical assessment, treatment principles, recurrence management, and long-term outcomes of clubfoot, emphasizing current evidence-based practices relevant to foot and ankle specialists.

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

Keywords: Clubfoot; Congenital talipes equinovarus; Ponseti method; Pediatric foot deformities.

Introduction

Congenital clubfoot is a complex condition in which there is an evident deformity of the foot present at birth, and that also involves the leg, where calf atrophy can be observed. This atrophy is present from the neonatal period, and it becomes more evident with growth. Although this atrophy is less noticeable in bilateral cases, it is important to inform parents from the outset that it is an intrinsic feature of clubfoot and not a consequence of the treatment. Placing a silicone implant to augment the calf may be considered after skeletal maturity; however, this is purely for aesthetic purposes, as the atrophy does not impair limb function (Figure 1)[1,2].

The main characteristics of clubfoot are equinus and varus of the hindfoot, cavus of the midfoot, and adduction of the forefoot. Clubfoot is a condition that has long been surrounded by controversy in almost all aspects, from its etiology and pathological anatomy to methods of evaluation and types of treatment. In fact, regarding treatment methods, clubfoot has undergone an exciting shift in recent years. Many orthopedic centers have reported a marked decline in the number of patients requiring extensive surgical releases for clubfoot. We have observed a historical shift toward abandoning an almost exclusively surgical approach by orthopedists treating this severe deformity, in favor of a more functional and less aggressive approach, driven by the enormous worldwide impact of the conservative Ponseti method, as will be discussed throughout this review[3-7].

Nevertheless, as Ponseti himself noted, recurrence occurs; some feet do not respond as well to his method, and surgical releases may be required[3].

Incidence

Clubfoot is one of the most common congenital deformities of the foot. Its incidence varies widely throughout the world according to race and sex. It is particularly high in Southeast Asia, where it may reach up to 7 per 1,000 live births.

In Brazil, particularly in São Paulo, an incidence of 2.17 per 1,000 births was observed[8], while in the United States, the incidence is around 1 per 1,000 births. Males are affected more often than females in a 2:1 ratio. Bilateral involvement occurs in approximately 50% of cases, and when only one side is affected, the right side has a slightly higher incidence than the left[7-9].

Study performed at Escola Paulista de Medicina, Universidade Federal de São Paulo, São Paulo, SP, Brazil.

Correspondence: Alexandre Francisco de Lourenço. Rua José Maria Lisboa, 1370, Apto 41, 01423-002, São Paulo, SP, Brazil. **Email:** alex.dot@uol.com.br.
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Etiology

The etiology of clubfoot remains unknown, with limited substantive advances reported in the literature to date. Several theories have been proposed involving neurological, muscular, mechanical-postural, and hereditary factors.

There is even a theory of arrest of embryonic development proposed by Bohm (1929)[10], who noted that the characteristics of the feet of a fetus between six and eight weeks of gestation are very similar to those of clubfoot, including equinus, supination, forefoot adduction, and medial deviation of the talar neck. On the other hand, talonavicular dislocation, which is one of the most recognized alterations in clubfoot, is not present at any stage of normal foot development[7,10].

Irani and Sherman dissected 11 clubfoot specimens and concluded that the primary defect was deviation of the anterior portion of the talus. They suggested that the abnormality of the talus resulted from a germplasm alteration[11].

MacNicol and Nadeem studied 95 feet initially diagnosed as idiopathic clubfoot and observed that 46% showed abnormalities in somatosensory evoked potentials, suggesting an underlying neurological pathology[12]. Undoubtedly, there is an association between several neuromuscular disorders and equinocavovarus deformity of the feet, such as arthrogryposis and myelomeningocele. On the other hand, the occurrence of isolated deformity in children without other abnormalities, as observed in idiopathic cases, argues against an exclusively neurological origin for clubfoot.

Rigidity of the soft tissues on the medial side was demonstrated by Ippolito and Ponseti, who identified an increase in collagen fibers in the ligaments and tendons of clubfoot. They studied five clubfeet and three normal feet from aborted fetuses between 16 and 20 weeks of gestation and found alterations in the shape, size, and articulations of the tarsal bones. They also noted a decrease in muscle fibers in the posteromedial portion of the distal third of the leg and an increase in connective tissue in the adjacent muscles, tendons, and fascia. Thus, they concluded that fibrotic retraction might be the primary etiological factor of clubfoot[13]. However, this deformity can also be observed in patients with marked ligamentous laxity, such as those with Down syndrome.

Regarding genetic contribution, it is known that heredity follows a polygenic pattern, since the risk decreases with lower degrees of kinship, increases when both parents have clubfoot, and also increases when more than one family member is affected. Recent evidence suggests that genes involved in limb development, apoptosis, and muscle function may contribute to the condition. A systematic review on the etiology of clubfoot has highlighted several of these gene families and pathways; however, a major candidate gene has not yet been identified[14].

Environmental factors, including maternal smoking, have also been associated with the development of clubfoot[15].

Pathology

Despite the lack of new evidence on the pathological anatomy of clubfoot, several characteristics should be recognized, including thickening and contracture of soft tissues, such as ligaments, tendons, and joint capsules. For many authors, the main alteration is talonavicular dislocation or subluxation, although medial deviation of the cuboid and calcaneus also occurs, producing hindfoot varus. The entire structure remains in equinus, resulting in the characteristic equinovarus deformity of clubfoot.

A circulatory alteration has also been described, consisting of hypoplasia or absence of the anterior tibial artery, which may be present in many cases and has important implications in surgical anatomy, since the medial surgical approach may compromise the posterior tibial artery, which may represent the main vascular supply to the clubfoot[16].

Many years ago, even before the use of sophisticated imaging techniques, it was already described that medial and plantar deviation of the navicular, cuboid, and calcaneus occurs around the talus. There is also a parallelism between the axes of the talus and calcaneus, both in the anterior and lateral views.

The Kite angle, a radiographic parameter formed by the axes of the talus and calcaneus on the anteroposterior view, is decreased, demonstrating hindfoot varus.

Figure 1. Calf atrophy is readily apparent at initial presentation, before treatment begins.

Although all soft tissue alterations involving the tendons and ligaments of the posterior and medial portions of the foot are important, the main component of the deformity in clubfoot is the medial displacement of the navicular-calcaneus-cuboid complex relative to the talus.

The talus itself presents with its distal extremity deviated plantar and medially, and its declination angle, formed by the axes of the neck and body, is significantly decreased. In the normal talus, this angle measures approximately 160°, whereas in clubfoot it is close to 90°.

Despite the supinated appearance of the foot, the forefoot is pronated relative to the hindfoot (plantar flexion of the first metatarsal), which is responsible for the cavus deformity. Soft tissue contractures maintain the disarrangement among bones and joints.

Intrinsic bone deformities are also present, such as the altered shape of the talus, which has a shortened neck due to its altered declination angle. This leads to alterations in the relationships between the bones of the clubfoot.

Because of the intrinsic talar deformity and the malposition of the navicular–cuboid–calcaneus complex, the talar head becomes dislocated relative to the so-called "acetabulum pedis."

As a result of medial deviation of the navicular, a false articulation may occur with the medial malleolus, and the lateral part of the talar head remains uncovered.

At the inferior portion of the talus, alterations of the subtalar joint facets may also occur, and the calcaneus may present with a poorly developed sustentaculum tali.

Although there is still controversy regarding the presence of internal tibial torsion associated with clubfoot, it is more likely that this represents a clinical appearance resulting from malposition of the talus within the ankle mortise[3,17,18].

Herzenberg et al.[19], using three-dimensional reconstructions of fetal specimens, demonstrated marked talar dysmorphism, including increased internal rotation of both the talus and the calcaneus relative to the ankle mortise. Although the talar body may appear externally rotated, the overall alignment is one of internal rotation, driven by deformity of the talar neck and medial displacement of the articular surface.

Diagnosis

Currently, prenatal diagnosis can be made using ultrasonography. The advantages of prenatal diagnosis include the possibility of determining whether the deformity is isolated or associated with other abnormalities, as well as allowing counseling about the condition and explaining the treatment to the parents. The disadvantages include the stress that may affect the family, as well as a relatively high rate of false-positive diagnoses, meaning that after birth, the diagnosis is not confirmed. Even when prenatal ultrasonography is combined with genetic testing in the evaluation of clubfoot, distinguishing isolated cases from those associated with additional structural or genetic anomalies remains challenging (Figure 2)[20-22].

However, it is at birth that the diagnosis can effectively be made through physical examination. In evaluating a newborn with clubfoot, the initial priority is to rule out associated anomalies. The deformity is quite characteristic and involves both the leg, which shows calf atrophy, and the foot, which presents the equinocavovarus deformity. A complete physical examination is important for ruling out other abnormalities and classifying the type of clubfoot. It is important to differentiate idiopathic clubfoot from cases associated with neuromuscular or syndromic disorders. Among the aspects evaluated, we must always consider the deformity's rigidity and the presence of medial and posterior skin creases.

While in true clubfoot the deformity is obvious, sometimes normal feet may present a positional equinovarus posture, which can confuse the neonatologist or pediatrician. However, orthopedic examination easily demonstrates that these postural deformities are not a cause for concern and should not be labeled as congenital clubfoot.

Radiography or any other complementary examination is not necessary because a large part of the bones of the newborn are still cartilaginous, not visible on radiographs.

The association between clubfoot and developmental dysplasia of the hip (DDH) remains controversial, as does the need for routine ultrasound screening[23,24].

Despite the lack of consensus, it is prudent to screen for DDH, as evidence suggests that physical examination alone may fail to detect even severe cases[25]. When DDH is associated with clubfoot, management of the hip should take priority. It is well established that clubfoot does not require urgent treatment. In fact, it may even be preferable to begin casting at around one month of age (Figure 3)[26,27].

Figure 2. Clubfoot may be detected on a prenatal ultrasound.

Classification

Clubfoot may be an isolated deformity (idiopathic) or may be associated with other conditions. Thus, the following classification can be considered[6]:

Idiopathic

Neuromuscular

- Arthrogryposis
- Myelomeningocele

Syndromic

- Larsen syndrome
- Moebius syndrome
- Freeman-Sheldon syndrome
- Streeter syndrome

Postural

- Not a true clubfoot; usually does not require treatment and should not be referred to as congenital clubfoot.

In addition to the general classification described above, there have long been attempts to classify clubfoot according to the severity of the deformity, and numerous classifications exist in the literature.

Among the several classifications described, the most commonly used today are those proposed by DiMeglio and Pirani. Both authors suggest that their classifications can be used not only for the initial assessment but also for treatment follow-up[28,29].

DiMeglio classification

The DiMeglio classification is based on clinical evaluation through inspection and palpation. A scoring scale is used for each item evaluated. Four main parameters are assessed, each graded from 0 to 4, and four additional parameters are scored 1 point each if present. The four main parameters evaluated and graded according to reducibility are: 1) degree of equinus; 2) hindfoot varus; 3) forefoot adduction; 4) medial rotation of the calcaneopedal block (relationship between the axis of the foot and the axis of the leg when viewed from the front).

In addition to these parameters, four additional findings are evaluated, each receiving 1 point: 1) medial crease; 2) posterior crease; 3) cavus deformity; 4) generalized hypertonia of the child[28].

The total score ranges from 0 to 20, and according to this score, the deformity is classified as:

- 0-5: benign foot
- 5-10: moderate foot
- 10-15: severe foot
- 15-20: very severe foot

Pirani classification

The Pirani classification is based on the clinical evaluation of hindfoot and midfoot deformities. For each parameter assessed, a score is assigned: 0 (normal), 0.5 (mild/moderate deformity), or 1 (severe deformity). The total score ranges from 0 (normal foot) to 6 (severe deformity). Both the hindfoot and the midfoot contribute a maximum of 3 points each[29].

This classification has been widely used by practitioners who follow the Ponseti method, and its main advantage is that it is simple to remember and appears to have limited subjective influence and low interobserver variability. Actually, both the DiMeglio and Pirani classification systems have consistently demonstrated good interobserver reliability (Figure 4)[30].

Figure 3. In case of the association of clubfoot and developmental dysplasia of the hip, treatment of the hip takes priority, and the Tubingen brace may be preferable to the Pavlik harness in this context.

Treatment

Historically, when surgical treatment was not considered sufficiently safe, nonoperative methods predominated. With the development of new surgical techniques and the increased safety afforded by advances in anesthesia, there was a marked expansion in the surgical management of clubfoot, which remained the predominant approach from the 1960s through the late 1990s (Figure 5).

The publication of long-term follow-up studies of children treated with extensive surgical releases revealed high rates of complications, stiffness, and pain, combined with the general trend toward less invasive approaches in medicine, which led to renewed interest in conservative treatment methods[31].

In fact, for a long time, most orthopedists agreed that early conservative management should be the initial approach for congenital clubfoot. However, few considered conservative treatment to be the definitive treatment for most children with this deformity. In many cases, the casting used during conservative treatment was inadequate to achieve correction, and the child simply waited until reaching an age appropriate

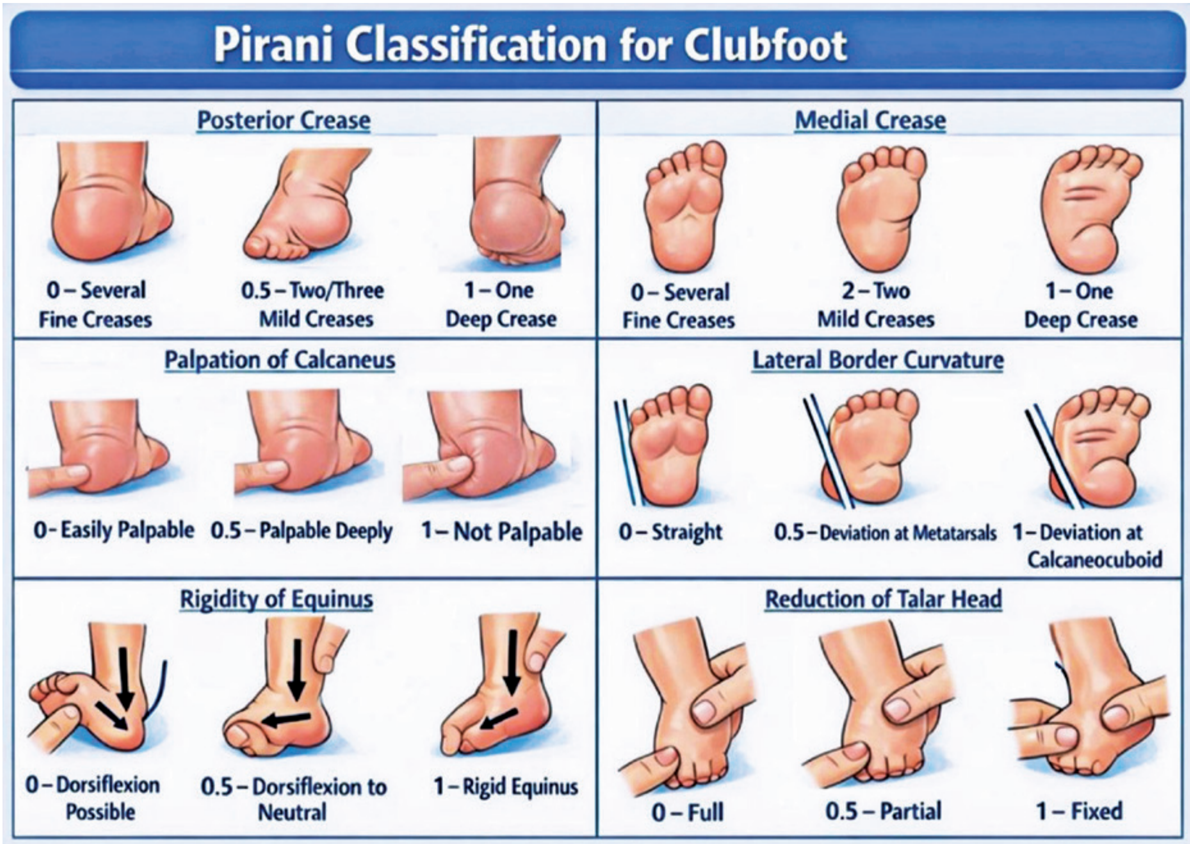

Figure 4. Pirani classification.

Figure 5. Extensive posteromedial and lateral releases for clubfoot is rarely indicated in current practice.

for surgery while undergoing temporary treatment with casts. This was particularly the case of the method described by Kite, who reported correction in up to 80% of cases. However, such correction rates were never consistently replicated by other authors, even though this method remained the most widely adopted conservative treatment worldwide for many years[32-34].

Interestingly, two other conservative and far more effective treatment approaches—the French functional method and the Ponseti method—were overshadowed for many years. The French functional method was adopted in very few centers outside France. Even among its original developers, the reported rate of initial correction was approximately 75%, which is lower than that achieved by most centers using the Ponseti method worldwide[35,36].

French Functional Technique

Bensahel et al. (1980) developed a functional treatment technique for clubfoot based on daily manipulations performed by physiotherapists, followed by immobilization using adhesive taping[35,36].

This method was later refined by DiMeglio et al. (1996), who introduced a passive motion machine that could be applied to the infants' feet for up to 16 hours per day. Using this treatment approach, these authors reported success in approximately 75% of patients (Figure 6)[37].

Although similar correction rates have been reported by other authors (even without using the passive motion machine), caution should be exercised when applying this technique. The deformity in clubfoot is extremely complex, and treatment may require surgical interventions that physiotherapists are not trained to evaluate or perform.

Ponseti method

Although described many years ago, the Ponseti technique remains one of the most modern contributions to the treatment of clubfoot[3,4].

The Ponseti technique involves manipulations and serial casting with long-leg casts changed weekly. This is perhaps the only similarity between this method and the Kite technique. Herzenberg et al.[34] conducted a comparative study of the two techniques and demonstrated the superiority of the Ponseti method.

The first major difference compared with the Kite method concerns the fulcrum used during foot abduction. Ponseti recommended that the head of the talus, palpated on the lateral side of the foot, should serve as the fulcrum (Figure 7).

The talus is stabilized within the ankle joint, and the entire foot is progressively abducted. This simultaneously corrects the talonavicular dislocation, the hindfoot varus, and the forefoot adduction. This simultaneous correction is another major difference compared with the Kite method. Casting should be performed by two people: the surgeon manipulates and maintains the foot in position while the assistant applies the cast. After manipulation, the foot should be immobilized in abduction with a long-leg cast, with the knee flexed at 90°. The cast must be well molded, and the toes should remain free to allow dorsiflexion. A relevant point to remember is that cavus should be corrected in the first cast, by stretching the plantar structures while maintaining the forefoot in supination relative to the hindfoot.

Figure 6. Continuous passive motion device used in Montpellier, France (courtesy of Alain DiMeglio).

Figure 7. The correct fulcrum to correct clubfoot is the talar head, not the calcaneocuboid joint, as demonstrated in the model developed by Dr. Ponseti.

The casts should be changed weekly, and parents are usually instructed to remove the cast at home shortly before the new appointment. Some practitioners prefer removing the cast at the clinic, depending on logistical considerations. Usually, about five casts are required even for severe deformities (Figure 8).

When correction of equinus is not achieved with manipulation and serial casting, percutaneous Achilles tendon tenotomy is indicated and is required in over 90% of cases. In the original technique, tenotomy is performed under local anesthesia, but many surgeons have preferred to perform it under general anesthesia. The advantage of the original technique is that it enables treatment in settings with limited hospital access. However, under general anesthesia, palpation of the tendon and casting are easier[38].

Another point of discussion concerns the type of blade used to cut the Achilles tendon, which can be performed using the tip of a No. 11 blade, an ophthalmic blade, or even a needle (Figure 9)[39,40].

After tenotomy, the foot is immobilized with a long-leg cast, with the ankle in 20° dorsiflexion and approximately 70° abduction, for three weeks.

Important points for successful treatment include:

- The child should remain calm; breastfeeding during casting is ideal but not always feasible
- Casting should be performed by two practitioners
- The foot should never be pronated
- The calcaneus should never be forced, only properly molded
- With progressive abduction, the initial supination gradually returns to neutral
- Achilles tenotomy should only be performed when equinus is the only remaining deformity.

After removal of the final cast, maintenance of correction is achieved using an abduction brace (often called the Denis-Browne brace).

The brace is applied with:

- 70° external rotation of the affected foot
- 10° dorsiflexion

It is worn full-time for three months, followed by nighttime use for three to four years.

In unilateral cases, the normal foot should be positioned in approximately 40° of external rotation.

The main difficulty with the method is brace compliance. Failure to use the brace is one of the most common causes of recurrence. Parents must therefore be strongly advised of the importance of proper brace use (Figure 10)[41].

Today, the Ponseti method is considered the standard treatment worldwide. However, even Ponseti acknowledged that about 5% of feet have very rigid ligaments that do not respond to manipulation and therefore require more extensive surgical correction[4].

Accelerated Ponseti

In the classic Ponseti method, the cast changes are done at weekly intervals, but to reduce the treatment time and less burden for families traveling long distances, some centers started using an accelerated protocol in which the manipulation and casting are done twice per week (every 3-4 days) with similar results[42,43].

Complex clubfoot

Complex (or atypical) clubfoot, as described by Ponseti et al.[44], represents a distinct subset of deformities, often observed in patients who have undergone prior manipulation or casting. It is characterized by severe equinus, a short

Figure 8. Most feet require approximately five serial cast changes to achieve correction before tenotomy.

Figure 9. A needle or a scalpel may be used to perform the tenotomy.

and stubby forefoot with a shortened first metatarsal, hyperextension of the great toe, marked plantarflexion of all metatarsals, and deep transverse plantar and posterior ankle creases.

Although many cases appear idiopathic, this pattern is frequently associated with improper casting technique, particularly slippage of the foot within the cast. Inadequate molding of the long-leg cast may allow slippage, resulting in abnormal forces that displace the calcaneus proximally, promoting further contracture and ultimately exacerbating the equinus deformity (Figure 11).

Early recognition of this condition is critical, as successful correction requires modification of the standard Ponseti method, typically employing the four-finger technique with careful attention to forefoot supination and controlled abduction. The knee should be maintained in 100° to 110° of flexion within the cast. Most cases can be corrected with a series of cast changes followed by Achilles tenotomy; however, the recurrence rate is higher in this type of clubfoot[45,46]. Even after correction, a complex clubfoot may present a lateral "break" at midfoot, and the abduction brace should initially be set at approximately 40° of abduction and gradually increased over subsequent weeks to 60°–70º (Figure 12).

Recurrence

Ponseti emphasized that clubfoot deformity tends to recur until approximately seven years of age. With careful supervision and adequate parental adherence, recurrences can be prevented in nearly 50% of patients. In the remaining cases, recurrence may occur between 10 months and 7 years of age.

When recurrence occurs, treatment should follow the same principles as the initial correction, with serial casting reintroduced. However, casts are typically changed at longer intervals (every 10-14 days) compared with the standard weekly protocol. Repeat Achilles tenotomy is frequently required, and in many cases, transfer of the tibialis anterior tendon to the lateral cuneiform is performed to address dynamic supination and reduce the risk of further recurrence. Therefore, when Ponseti reported correction rates approaching 90%, it is important to consider that these outcomes included management of recurrences, which often required additional procedures (Figure 13)[3,4].

Noncompliance with the use of the abduction brace is often cited as the primary cause of recurrence; however, this is not invariably the case, as highlighted by Mahan et al.[47]. In their study, recurrences in children younger than two years were strongly associated with inadequate brace use, whereas in children older than two years, recurrences occurred even in the presence of appropriate compliance, indicating that additional factors contribute to recur in this age group.

Figure 11. Poor casting technique is a major cause of complex clubfoot. A cast applied with less than 90° of knee flexion and inadequate molding can slip easily, exerting abnormal pressure on the calcaneus.

Figure 10. Brace compliance is a major challenge in the Ponseti method, regardless of the type used.

Figure 12. Early recognition of complex clubfoot is essential, and modification of the Ponseti manipulation protocol is required, including the use of the four-fingers technique. The abduction brace should be set at a lower degree of abduction to prevent the increase of the lateral midfoot "break".

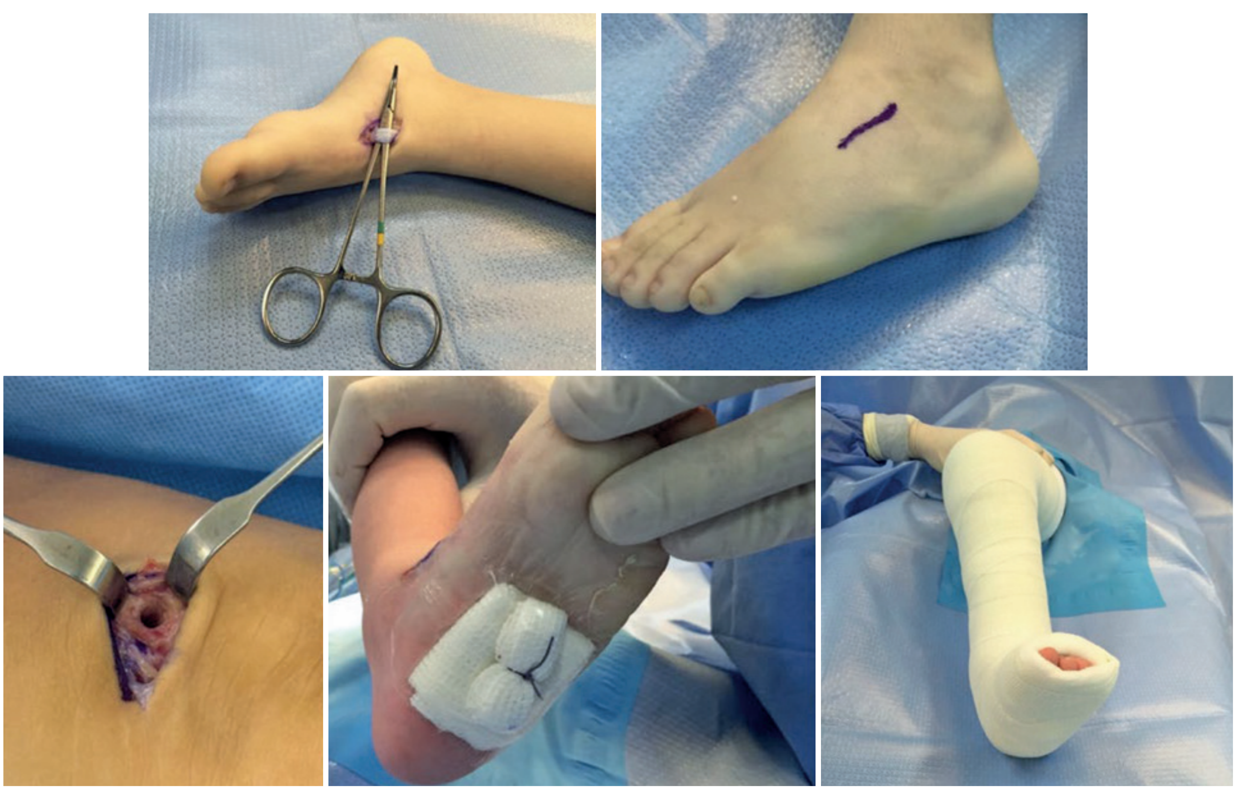

Figure 13. Anterior tibialis anterior transfer to the lateral cuneiform is often performed in cases of recurrence, preferably using the pull-out technique, followed by six weeks of long-leg casting.

One potential contributing factor to recurrence is insufficient activity of the evertor muscles, as suggested by Little et al.[48]. Notably, most components of the Ponseti method rely on passive interventions, including manipulation, casting, and bracing. In this context, strategies to stimulate muscle function may play an important role. In infants, this may be achieved through reflex-based stimulation, whereas in older children, active exercises can be introduced to promote foot eversion. Such approaches may be more effective than relying solely on prolonged brace use. Although this concept requires further investigation, it aligns with the hypothesis proposed by several authors and reflects my clinical experience, suggesting that targeted muscle activation may help reduce recurrence rates (Figure 14)[49,50].

The role of surgery in contemporary clubfoot management

Although the Ponseti method is widely described as a conservative treatment for clubfoot, it may be more accurately characterized as a minimally invasive surgical approach. While the initial correction relies heavily on serial manipulation and casting, approximately 90% of patients require a percutaneous Achilles (calcaneal) tenotomy to achieve adequate correction of equinus. This procedure, although minor, is undeniably surgical.

Furthermore, a subset of patients will subsequently require additional surgical intervention, most commonly a tibialis anterior tendon transfer, to address dynamic supination and reduce the risk of recurrence.

Therefore, rather than being purely conservative, the Ponseti method should be understood as a comprehensive treatment strategy that combines non-operative techniques with essential minimally invasive surgical procedures to optimize outcomes.

With the proper application of the Ponseti technique, the need for extensive surgical procedures has markedly decreased. The method has also been increasingly used for non-idiopathic and neglected clubfoot, with many patients benefiting from it. However, maintenance of correction in these groups is less predictable, and the need for additional surgical interventions remains higher[51-53].

Figure 14. Exercises may help maintain correction, initially with passive motion and stimulation of reflex evertor activity and later active motion and strengthening.

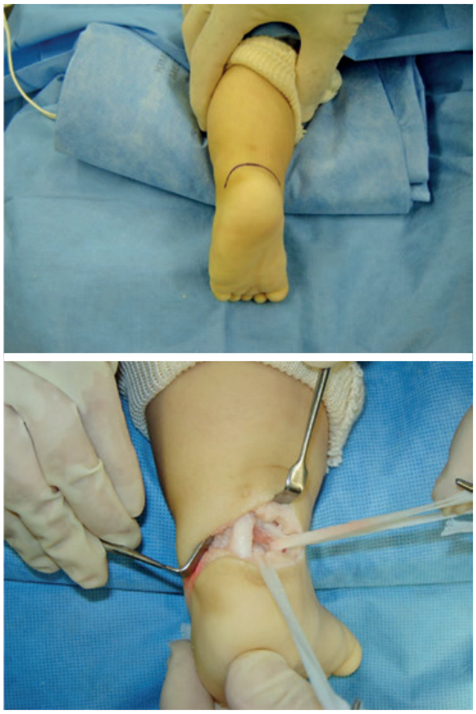

Figure 15. Surgery is limited to less extensive, targeted procedures, in accordance with the principle of "à la carte" release.

Therefore, despite these advances, surgery remains an important adjunct in selected cases. Indications for operative intervention include resistant deformities that fail to respond to appropriate Ponseti casting, recurrent clubfoot—often associated with poor brace compliance or persistent muscle imbalance—and residual deformities such as dynamic supination or persistent equinus. In these situations, modern surgical strategies favor limited, targeted procedures rather than extensive releases.

In addition, surgery may be required more frequently in non-idiopathic clubfoot, including neuromuscular and syndromic cases, which are characterized by greater rigidity and higher recurrence rates despite initial correction with the Ponseti method. Similarly, neglected or late-presenting cases often necessitate a combination of casting and surgical intervention, including osteotomies or gradual correction techniques.

Nevertheless, before considering surgical intervention, it is advisable to perform a period of manipulation and casting as a preoperative measure to reduce the extent of the procedure.

An individualized approach, as proposed by Bensahel, may represent the optimal strategy. In this concept of "à la carte" surgery, operative treatment is directed only at residual deformities that persist after conservative management, thereby avoiding extensive surgical exposure to preserve joint mobility and minimize long-term morbidity (Figure 15)[54].

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Special Article

Intra-articular calcaneal fractures: Update

Juan Manuel Yañez Arauz[1], Nicolás Raimondi[1]

1. Austral University Hospital, Buenos Aires, Argentina.

Abstract

Review the literature on the current treatment of intra-articular calcaneal fractures, analyze the results of the different treatments, and provide an overview of the subject, types, and controversies of treatments, complications, and sequelae. Articles published in indexed journals were analyzed. Most were published in the past 25 years and addressed the treatment of intra-articular calcaneal fractures.

Level of evidence V; Expert opinion.

Keywords: Calcaneus; Fracture fixation, internal; Treatment outcome.

Introduction

Calcaneal fractures occur infrequently, representing 1%-2% of total fractures. Approximately 60%-75% of calcaneal fractures are displaced intra-articular fractures[1,2]. These injuries typically occur due to high-energy trauma. The most common cause is a fall from height, followed by vehicular accidents[3]. In the injury mechanism, high-energy compressive forces flatten the bone, resulting in heel widening, loss of posterior heel height due to bone collapse, and articular surface injury[2]. As it is a pathology with a high incidence of occupational, social, and economic repercussions, adequate treatment is essential. Additionally, patients may have comorbidities, including diabetes and osteoporosis, aggravating complications and worsening the expected outcome for these fractures. A debate over the effectiveness of surgical treatment in these displaced articular fractures is common. Some authors claim that non-surgical treatment has similar results[4,5]. Current evidence remains insufficient to determine whether surgical treatment is superior to non-surgical treatment. However, other authors[6] have reported that non-surgical treatment frequently yields suboptimal outcomes, contributing to subtalar joint degeneration, malalignment, and poor functional recovery. Over the past few decades, several studies have shown improved outcomes following surgical treatment. Surgical intervention may lead to improved functional recovery, according to the meta-analysis by Jiang et al.[7]. Restoring normal anatomy is associated with improved functional recovery[8]. Surgical treatment has become the preferred option for most surgeons; however, the healing process of calcaneal fractures often results in functional sequelae, regardless of the treatment used[9].

Restoration of calcaneal anatomy and articular congruity is essential. Achieving adequate reduction and stable fixation, along with early mobilization are mandatory to optimize outcomes. Thorough knowledge of calcaneal anatomy and its anatomic relationships is crucial to achieve a satisfactory surgical result.

Anatomy

The calcaneus comprises trabecular bone surrounded by a slender cortical layer. The cortical shell supporting the subtalar facets is denser than the surrounding regions and is referred to as thalamic bone. Within the cancellous bone, traction and compression trabeculae are formed. Below the thalamic portion of the calcaneus, there is an area with sparse trabeculae, which is called the neutral triangle.

This region is regarded as the most fragile part of the bone, and as a result, most fractures happen here[10]. The Gissane angle (Figure 1) is formed by the intersection of the downward and upward slopes of the superior calcaneal surface. It is located directly inferior to the lateral process

Study performed at Austral University Hospital, Buenos Aires, Argentina.

Correspondence: Juan Manuel Yañez Arauz. Austral University Hospital, Buenos Aires, Argentina. **Email:** jmyanez@cas.austral.edu.ar. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** May 28, 2025. **Date accepted:** February 05, 2026.

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of the talus[11]. Its normal value is 95º-105º, and its decrease reflects the presence of a compression fracture.

Classic fracture mechanism

These fractures are high-impact injuries, generally caused by falls from height, with force applied in a vertical direction from the plantar. The talus is a much denser bone that acts as a wedge on the subtalar joint. The calcaneus fractures, with collapse of its articular surface, elevation of the greater tuberosity, and widening of the lateral wall, which is the weakest. The pattern of fracture lines and the degree of comminution vary and depend on several factors, including the position of the foot at the time of impact and the patient's overall bone quality[12].

On physical examination, the patients cannot bear weight and present with edema, ecchymosis at the heels, and diffuse pain. Generally, the ecchymosis extends through the plantar arch. There is flattening, heel widening, and loss of heel height. It is mandatory to perform a complete neurovascular examination and evaluate lower-extremity tendon function. Some cases present blood blisters.

Bony evaluation in the emergency room

Anteroposterior, lateral, and oblique plain radiographs of the foot are needed[13]. A Harris view may be obtained, which demonstrates the calcaneus in an axial orientation. Bohler's angle is generally decreased, and the critical angle of Gissane is increased, on plain radiographs. Normal Bohler's angle is between 20º and 40º. Normal Gissane angle is between 130º and 145º. Computed tomography (CT) scan remains the gold standard for traumatic calcaneal injuries. It is used for preoperative planning, classification of fracture severity, and when the suspicion for a calcaneal fracture is high despite negative initial plain radiographs.

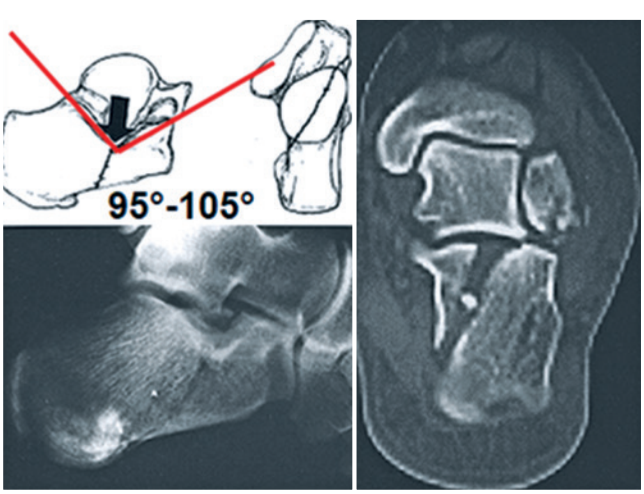

Figure 1. Gissane angle. Normal values and fracture force action.

Sanders' classification[9] is widely used, dividing the calcaneus into four columns based on fracture pattern. It is based on a coronal CT scan. There are 4 types: (Figure 2).

Type I fractures: nondisplaced bony fragments.

Type II fractures: two displaced bony fragments involving the posterior facet. Subdivided into types A, B, and C depending on the medial or lateral location of the fracture line.

Type III fractures: three displaced bony fragments. Subdivided into types AB, AC, and BC, depending on the position and location of the fracture lines.

Type IV fractures: four displaced, comminuted bony fragments.

Its limitations include limited assessment of concomitant fracture lines or soft-tissue damage.

Discussion

Conservative treatment

Lewis et al.[14] compared the outcomes of conservative and surgical treatments for displaced fractures. They noted that evidence suggests that surgical treatment could improve the functional outcomes. But they mention that the surgery may carry a higher risk of unplanned interventions. However, the authors found no difference between treatment options in the number of patients who required late reconstruction surgery

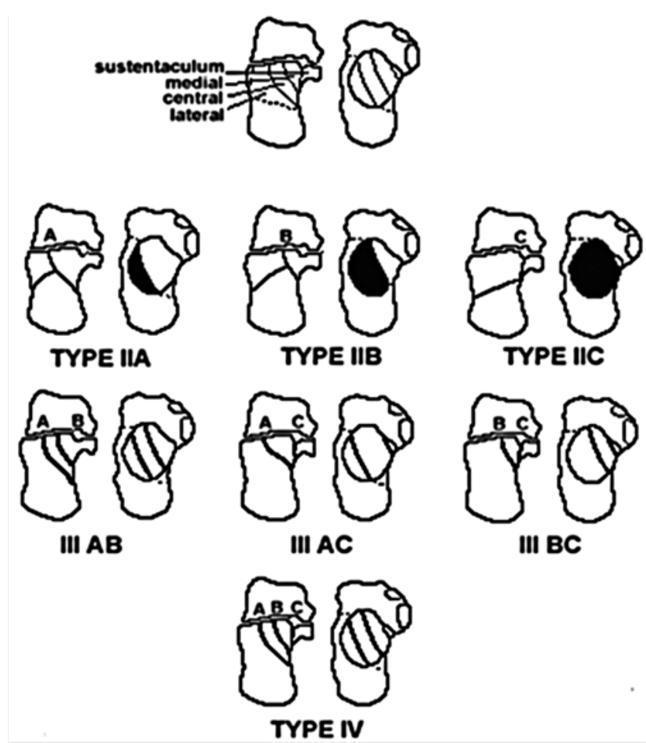

Figure 2. Sanders classification. Coronal slices in a computed tomography scan.

for subtalar arthritis. They conclude that further studies are necessary to draw more certain conclusions.

Pozo et al.[15] reported that calcaneal deformities commonly develop after intra-articular fractures that were not properly reduced or treated nonsurgically. But it can also occur after surgical treatment. There is an inverse relationship between the number of surgical cases and postoperative subtalar arthrosis[16]. This indicates that a genuine learning curve exists in the surgical management of these fractures.

Therefore, there is consensus that conservative treatment is reserved for non-displaced fractures (Sanders type I). Treatment involves rest, ice, non-weight bearing, anti-inflammatory medication, and early mobilization.

Surgical treatment

The surgical treatment of intra-articular calcaneal fractures has evolved significantly in recent years, particularly with the development of less invasive surgical approaches. Although open reduction and internal fixation (ORIF) remains the standard treatment in many cases, minimally invasive techniques (MIS), percutaneous fixation, and primary arthrodesis have emerged as valid therapeutic alternatives, especially in selected patients.

Open reduction and internal fixation via the extensile lateral approach (Figure 3) has historically been the technique of choice for displaced fractures involving the subtalar articular surface. Makki et al.[17] reported a mean AOFAS score of 75 with a mean follow-up of 10 years. This approach provides excellent exposure of the posterior facet, tarsal sinus, and sustentaculum tali, facilitating accurate anatomical reduction. Low-profile locking plates have improved construct stability and reduced mechanical failure rates, but soft tissue morbidity remains a major concern. Some authors[18] reported a mean AOFAS score of 74 points, with a minimum follow-up of 20 years. Complications associated with the lateral approach include wound dehiscence, skin necrosis, deep infection, and sural nerve injury. These complications occur in 15% to 30% of cases, particularly in patients with risk factors such as smoking, diabetes, or severe edema[19,20]. For this reason, its indication has become more selective and is now reserved for fractures with severe comminution or significant calcaneal collapse.

Minimally invasive techniques have become an intermediate option between ORIF and purely percutaneous fixation. The most commonly used approach is the sinus tarsi (Figure 4), which is performed through a 3-4 cm incision. This technique allows direct visualization of the subtalar joint without em-

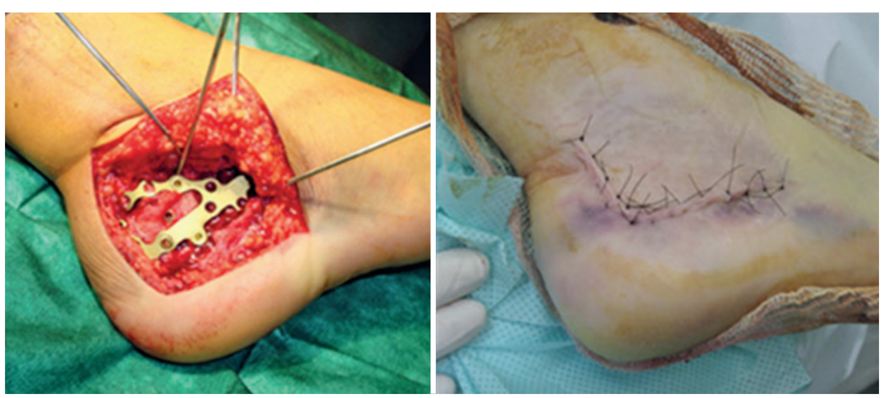

Figure 3. Lateral extensile approach.

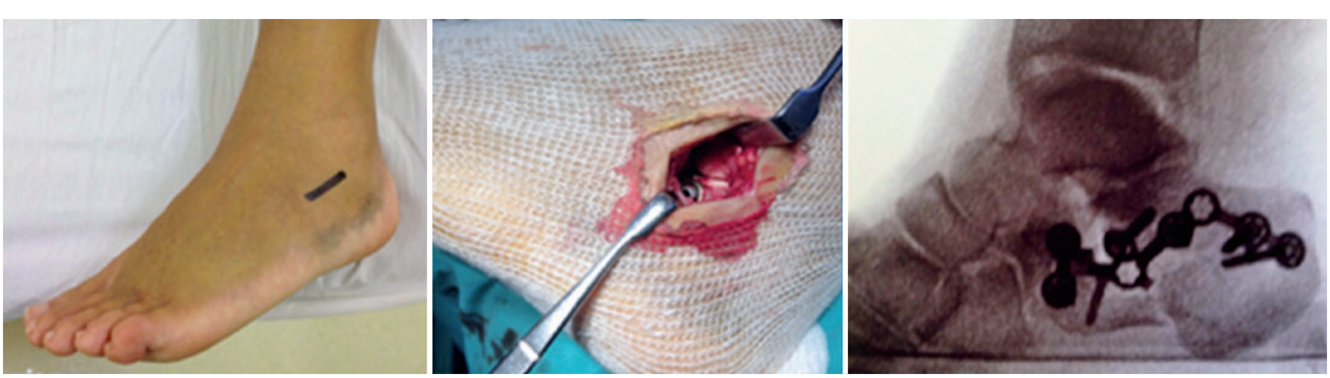

Figure 4. Sinus tarsi approach.

ploying a large incision. Clear delineation of the posterior subtalar and calcaneocuboid joints enables proper reduction of these joints, thereby preventing misalignment[21]. This technique enables a limited direct-vision-assisted anatomical reduction followed by placement of specific low-profile screws or plates. Recent studies have shown that MIS provides functional outcomes comparable to ORIF and a significant reduction in wound-related complications. [22]. In a systematic review of 271 calcaneal fractures repaired using the sinus tarsi approach, a lower incidence of wound complications and fewer sural nerve injuries were observed compared to the extensile lateral approach[23]. Furthermore, this technique allows for faster recovery and shorter hospital stays. The sinus tarsi approach is advantageous in Sanders type II and some type III fractures, where the integrity of the sustentaculum tali is preserved, and comminution is limited. However, it requires a specific learning curve, and its indication should be carefully considered in fractures with medial collapse or severe central comminution. Regarding implant removal, De Boer et al.[24] reported an overall removal rate of 35%. Of these, 66% had been treated by the tarsal sinus approach.

Percutaneous fixation is an even less invasive surgical strategy than MIS. This is performed by indirectly reducing the calcaneus via externally controlled maneuvers under fluoroscopy, followed by stabilization with cannulated screws. This technique, described by Forgon and Zadravecz[25], was developed to reduce the rate of wound complications. This method aims to restore articular congruity and bone morphology without the need for extensive incisions. It is especially indicated in patients at high risk of soft tissue complications (e.g., smokers, diabetics, immunosuppressed individuals), and fractures without severe comminution, where acceptable reduction can be achieved indirectly. Biomechanically, percutaneous fixation has been shown to provide adequate stability in simple fracture patterns, with functional results comparable to ORIF in long-term series[26,27]. However, this technique has clear limitations: indirect reduction may be incomplete in cases of severe posterior facet impaction, and intraoperative control heavily depends on image quality and surgeon experience. Driessen et al.[28], using this technique, reported in their long-term study that an AOFAS score of 76 points was achieved at a mean follow-up of 16 years.

Primary subtalar arthrodesis has gained acceptance as a valid therapeutic option in highly comminuted intra-articular fractures, particularly in elderly patients, those with preexisting osteoarthritis, low functional demand, or poor prognosis for joint reconstruction. Considered in Sanders type IV or those with significant articular damage in workers. The goal is to provide a stable, plantigrade, and pain-free hindfoot, avoiding progression to symptomatic post-traumatic osteoarthritis. It can be performed via a lateral approach or percutaneously. Depending on the degree of bone collapse, partial reconstruction of the calcaneal body may be required using structural grafts. Studies show that this technique can yield functional outcomes comparable to ORIF in type IV fractures, with lower rates of reoperation due to secondary arthritis and higher patient satisfaction in selected populations[29]. A 2022 systematic review[30] found that primary arthrodesis in severely comminuted fractures (Sanders IV) reduces the rate of late complications after ORIF, and 13.63% of ORIF cases required secondary subtalar arthrodesis. However, functional outcomes did not differ significantly between arthrodesis and ORIF.

External fixation

Talarico et al.[31] reported 25 intra-articular calcaneal fractures that were treated with external ring fixation. He described good to excellent outcomes in 23 at the final follow-up. External fixation offers benefits such as prompt weight-bearing, controlled distraction with minimal pain, mainly in soft-tissue injuries and severe comminution, and a low likelihood of complications. Frequent issues observed with external fixation include pin-related complications such as pin tract infection, neurovascular injury, and implant failure. Nowadays, it plays a role in open calcaneal fractures, those with severe soft tissue compromise, or as a bridging technique in polytrauma patients. It may be combined with percutaneous screws (hybrid configurations) as a temporary stabilization strategy that preserves hindfoot vascularity during damage control.

Table 1 summarizes the therapeutic options and considerations by fracture type.

Surgical and post-surgical complications

Surgical treatment of intra-articular calcaneal fractures, regardless of the technique used, is associated with several complications that can significantly impact functional outcomes. These complications can generally be classified as early (surgical) and late (post-surgical), and their incidence varies depending on the surgical approach, fracture severity, and patient comorbidities.

Skin complications remain a major concern in calcaneal surgery, particularly with open approaches. Wound edge necrosis, dehiscence (Figure 5), and superficial or deep infection are the most frequent. Reported incidence ranges from 12% to 30% in extensile lateral approaches[19]. Preoperative risk factors that predispose to wound breakdown include smoking, diabetes, open fractures, high body mass index, and

Table 1. Surgical options by Sanders fracture type

Sanders fracture type	Recommended technique	Key considerations
Type I	Conservative treatment	No displacement
Type II	MIS (Sinus tarsi) / Selective ORIF	Preserved sustentaculum tali
Type III	MIS or ORIF	More comminution, visualization needed
Type IV	Primary subtalar arthrodesis / External fixation	Severe joint destruction

MIS: Minimally invasive techniques; ORIF: Open reduction and internal fixation.

closure of the incision in a single layer[32,19]. Recent studies show that MIS and percutaneous techniques dramatically reduce these complications, with deep infection rates under 3% and wound dehiscence under 5%[20,21]. Shorter surgical times, minimal subcutaneous dissection, and preservation of lateral hindfoot vascularization are protective factors.

Injuries to the sural nerve, superficial peroneal nerve, or branches of the posterior tibial nerve may occur. The incidence of transient paresthesia is approximately 5%-10%, and permanent symptoms occur in less than 2%[23]. Anatomical landmarks and precise knowledge of neurovascular pathways are essential for prevention.

One of the most frequent medium- and long-term complications is the development of subtalar osteoarthritis (Figure 6), secondary to inadequate articular reduction, cartilage necrosis, or residual incongruity. Treatment of secondary osteoarthritis may include conservative measures or surgical procedures, with subtalar arthrodesis being the most effective method for pain relief in advanced cases.

Figure 5. Wound dehiscence.

Deep infections remain a feared complication. Although their incidence has decreased with MIS and percutaneous techniques, they can still reach up to 6% with open approaches, particularly in the presence of predisposing factors such as smoking, diabetes, obesity, or open fractures[19]. Management includes prolonged antibiotic therapy, surgical irrigation, and, in advanced cases, extensive debridement or salvage arthrodesis. Table 2 presents complications associated with surgical techniques.

Table 2. Complication rates by surgical technique

Surgical technique	Wound complications (%)	Symptomatic subtalar arthritis (%)	Reoperation rate (%)
ORIF (lateral approach)	15–30	28	13.6 (due to arthritis)
MIS (sinus tarsi)	5.4	19	~6–10
Percutaneous	<5	15	Higher if inadequate reduction
Primary arthrodesis	<10	-	Low
External fixation	~10 (pin site infection)	-	Low

MIS: Minimally invasive techniques; ORIF: Open reduction and internal fixation.

Table 3. Criteria for selecting surgical approach

Patient / Fracture condition	Preferred surgical technique	Clinical justification
Healthy patient, no comorbidities	ORIF (extensile lateral approach)	Allows full anatomic reduction in complex fractures
Severe edema or soft tissue compromise	MIS or external fixation	Less soft tissue trauma
Diabetic / smoker / immunosuppressed	Percutaneous or MIS	Lower risk of infection and wound issues

MIS: Minimally invasive techniques; ORIF: Open reduction and internal fixation.

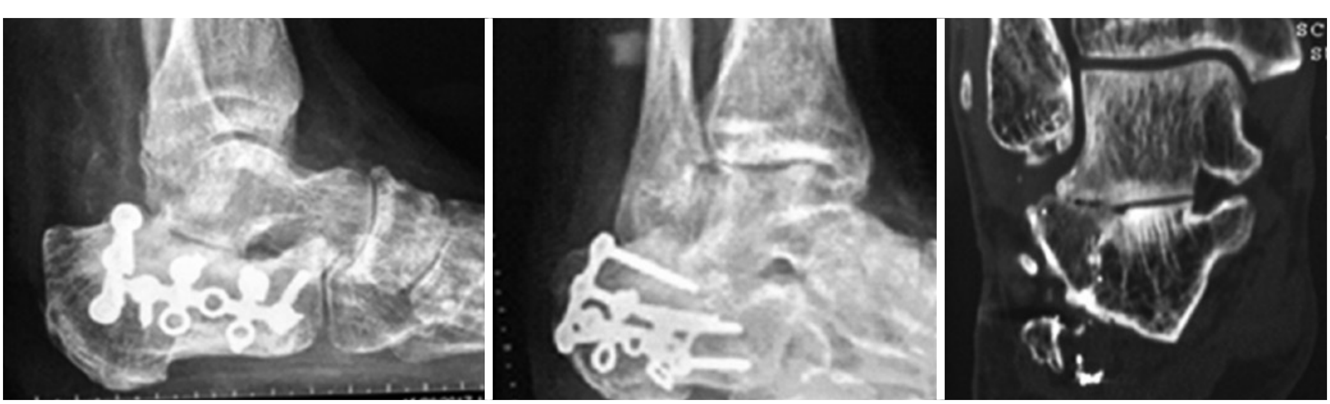

Figure 6. Calcaneal fracture sequelae. Subtalar osteoarthritis.

Conclusions

Calcaneal fractures involving the joint remain a complex issue for orthopedic management. Although no single treatment modality has proven superior in all cases, recent evidence supports surgical intervention for displaced fractures, particularly when anatomic reduction can be achieved. Minimally invasive techniques and percutaneous fixation have gained prominence due to their favorable complication profiles and functional outcomes comparable to those of traditional open reduction and internal fixation. Primary subtalar arthrodesis and external fixation are valuable alternatives in specific patient populations and fracture patterns. Table 3 summarizes the criteria for selecting an approach to these fractures. Ultimately, treatment should be individualized based on fracture type, patient comorbidities, soft tissue condition, and surgeon expertise. More well-designed comparative studies are necessary to enhance decision-making and long-term outcomes in this complex injury.

Authors' contributions: Each author contributed individually and significantly to the development of this article: JMYA *(https://orcid.org/0000-0001-5739-3130) and NR *(https://orcid.org/0000-0002-2561-8590); Conceived and planned the activities that led to the study; interpreted the results of the study and participated in the review process; performed the surgeries and data collection.

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Special Article

Percutaneous management of posterior malleolar fractures

Tomas Urrutia[1], **Jafet Massri-Pugin**[1], **Sergio Morales**[1], **Jorge Filippi**[1]

1. Red de salud UC Christus, Santiago, Región Metropolitana, Chile.

Abstract

Posterior malleolar fractures (PMF) are present in up to 44% of ankle fractures. Despite its frequency, there is controversy over the fixation criteria and optimal technique. Historically, fragment size (> 25%) was used as a surgical indication, but today, criteria such as syndesmotic instability, articular step-off, and fragment morphology are used. To synthesize evidence on the percutaneous fixation of PMFs, analyze their indications and risks, compare them with the open approach, and describe the surgical technique preferred by the authors. Percutaneous fixation offers advantages such as the preservation of soft tissues and shorter surgical time in the supine position. However, studies show a higher malreduction rate than open reduction and internal fixation (ORIF) (up to 73% vs. 17%), especially in comminuted or displaced fragments ≥ 5 mm. In single-fragment fractures with minimal displacement, the functional results are comparable. Recent literature suggests that posteroanterior (PA) fixation is biomechanically superior and presents better clinical outcomes and lower rates of osteoarthritis than the anteroposterior (AP) technique. Percutaneous fixation is a valid and effective alternative in selected cases of simple, noncomminuted, minimally displaced PMFs, as well as in patients with low functional demand or soft-tissue compromise. The PA technique stands out for its stability. Success depends on proper computed tomography planning and the surgeon's willingness to convert to an open approach if anatomical reduction is not achieved through indirect maneuvers.

Level of Evidence V; Expert opinion.

Keywords: Posterior malleolus; Ankle fractures; Minimally Invasive Surgical Procedures.

Introduction

Ankle fractures account for up to 10% of all fractures, and posterior malleolar involvement occurs in 7% to 44% of these[1-3]. Posterior malleolar fractures (PMF) are located at the posterior edge of the articular distal end of the tibia and include a wide variety of fracture patterns, being more frequent in the posterolateral edge[4-6].

To analyze PMF, it is essential to complement the evaluation with computed tomography (CT), as this modality allows accurate assessment of anatomy, displacement, and comminution, thereby guiding surgical behavior in approximately one-third of cases[2,7]. However, there is still no consensus on when or how PMF should be treated surgically, or on what degree of malreduction is acceptable without compromising functional outcomes in patients[1,3,6,8,9].

The classic indications for PMF management are based on low-quality evidence and have been questioned as a criterion to define behavior[10] in favor of other parameters, such as tibiotalar or syndesmotic instability, articular step-off, impact, comminution, morphology, and commitment of the

Study performed at the Red de salud UC Christus; Santiago; Región Metropolitana, Chile.

Correspondence: Tomas Urrutia. Marcoleta 367, Santiago, Región Metropolitana, 8330024, Chile. **Email:** tomurrutiaj@ucchristus.cl. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** April 04, 2026. **Date accepted:** April 04, 2026.

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incision and evidence of better functional outcomes when fixing fragments less than 25% of the articular surface[1,3,11-14]. In addition to the questionable indication for fixing these fragments, there is great heterogeneity in how PMF is handled, particularly with Bartoníček 2 and 3[15].

The objective of this narrative review is to synthesize evidence on the percutaneous fixation of PMFs, analyze their indications and risks, compare them with the open approach, and describe the surgical technique preferred by the authors.

Open approach vs percutaneous fixation

When deciding on posterior malleolus surgery, several factors should be considered during planning. A posterior approach requires the surgeon to position the patient prone, which can make it difficult to treat associated injuries; however, with percutaneous management, the patient can remain supine.

Verhage et al.[3], in a systematic review comparing open and percutaneous management, concluded that there is an increased risk of progression to osteoarthritis in patients with a postoperative articular step-off. The incidence of this articular step-off was 8%-17% with open reduction and internal fixation (ORIF) versus 17%-73% with percutaneous fixation. In addition, better results were reported on the AOFAS scale with ORIF. While this meta-analysis does not provide definitive guidance, it highlights the importance of anatomical reduction for optimal functional outcomes.

On the other hand, the meta-analysis by Wang et al. [13] did not demonstrate differences in clinical scores between the two methods, although they observed a greater reduction, a lower non-union rate, and a greater loss of dorsiflexion with ORIF. In contrast, percutaneous osteosynthesis significantly reduced the risk of infection and neurological injury

Haws et al.[1] evaluated the rate of malreduction in a retrospective series of 120 patients (75.8% ORIF and 24.2% percutaneous). A significant difference was observed in favor of the ORIF (7.7% vs. 24.1% malreduction). After analyzing the risk factors, it was concluded that comminuted fractures or fractures with initial displacement ≥ 5 mm have a higher risk of malreduction with percutaneous treatment. In single-fragment fractures, there were no significant differences across methods. There were no differences in complications or PROMs at 1-year follow-up between the two groups.

Based on this information, we believe that percutaneous management of PMFs has a clear role in treating single, non-displaced, or minimally displaced fragments. This group of patients benefits the most, since the quality of the reduction is not sacrificed, the rigidity associated with subsequent approaches is avoided, and the soft tissues are protected.

Likewise, in patients with low functional demand, advanced age, or with comorbidities that require minimizing surgical aggressiveness, percutaneous management should be considered. In these cases, a suboptimal reduction could be accepted, always after an informed discussion with the patient about the risks and benefits of this choice[16].

Anteroposterior percutaneous screw

Traditionally, the most common indirect fixation technique for PMFs has been the anteroposterior (AP) screw method[7,17]. This technique is ideal for large posterolateral fragments and should be performed prior to definitive fixation of the medial and lateral malleoli to allow better visualization of the articular surface reduction[7].

In Haraguchi type 1 and small fragments, fixation with an AP-cannulated screw is usually considered sufficient[18,19]. In cases of larger fragments, the use of more than one screw may be chosen, at the discretion of the surgeon, to achieve adequate stabilization. Since this technique is strictly dependent on intraoperative imaging support to ensure correct material orientation, it is imperative to consider the concave morphology of the tibial surface and the anatomy of the syndesmosis. The height of the screw is easily evaluated on a lateral radiograph, verifying that its position is extra-articular (with respect to the tibiotalar joint). In addition, this view allows confirmation that the screw length is appropriate and that it crosses the fracture line. To confirm the position in the AP view, the posteromedial vertical syndesmotic line (PVSL) is used as a safety limit to avoid intra-syndesmotic screw placement[20]. The authors also concluded that the PA screw should be located 12 mm medial to the PVSL to avoid injury to the flexor hallucis longus (FHL) tendon. Another issue with this technique is the lack of compression or weak fixation when handling very small fragments, in which the threads cannot cross the fracture line, thereby failing to securely hold the PMFs[21]. Finally, lesions of the tibial and superficial peroneal nerves, the extensor hallucis longus (EHL), the anterior tibial tendons, and the anterior tibial artery have also been described[16,22].

Posteroanterior screw

To address the limitations of percutaneous AP fixation, percutaneous PMF fixation by posteroanterior (PA) screw has gained popularity. Strenge and Idusuyi[23] pioneered a percutaneous PA technique in which the entry point was medial to the anterior tibial tendon. A 1.6 mm anteromedial to posterolateral Kirschner wire (K-wire) was inserted into the ankle during dorsiflexion, and the Achilles tendon was displaced medially to avoid damage. Then, a partially threaded screw is inserted from posterior to anterior. The correct insertion site is crucial to prevent damage to the tibiotalar cartilage when using a PA screw. Using a digital caliper, a prospective study[24] of 100 dry tibia bones showed that screw placement parallel to the tibiotalar joint should be 6 mm and 5 mm above the distal edge of the posterior malleolus for men and women, respectively. If the screw is inserted distal to that reference, they recommended that the screw should be angled 18° and 15° for men and women, respectively, to avoid damaging the articular surface. Although this study was conducted under direct visualization, the results can be applied to the percutaneous technique.

Kimball et al.[25] analyzed the risk of injury in 15 cadaveric specimens using the percutaneous PA technique. The orientation was from the anterior-anterolateral area of the tibia, and a K-wire was advanced in the posterolateral direction. They reported that the sural nerve and peroneal artery had mean wire distances of 5.3 mm (range, 0 to 12 mm) and 5.7 mm (range, 2 to 13 mm), respectively, with no traumatic perforations of either structure. The authors concluded that this technique is a safe alternative with a low risk of tendon and neurovascular injury and recommended it for noncomminuted and minimally displaced fractures and for patients with fragile soft tissues. For their part, Clarke et al.[26] conducted a cadaveric study, where they did not report lesions of neurovascular or tendon structures with this technique, but Czerwonka et al.[27] did report that the sural nerve was in contact with the wire in one specimen, and was sectioned in a second specimen of the 10 evaluated. In addition, the guide-wire pierced the belly of the FHL in four specimens, but the tendon was not damaged by the screw. They concluded that the risk of neurovascular injury was low and suggested using a mini-open approach to protect the sural nerve, and cautioned against using a washer or large-head screws due to the risk of FHL injury.

Percutaneous fixation PA versus AP

The literature comparing percutaneous PA versus AP fixation for PMFs is limited. Yu et al.[28] evaluated 76 patients with trimalleolar ankle fractures of PMF Haraguchi type I. Patients were randomly assigned to percutaneous AP fixation (36 patients) or PA (40 patients), and the authors compared their clinical, radiological, and patient-reported outcomes with a mean follow-up of 30 months. No differences were found between the groups in terms of surgical time, range of motion, or visual analog scale score. However, the rates of severe post-traumatic ankle and articular step-off osteoarthritis were significantly higher in the AP screw group. They concluded that PA fixation is a reliable option for treating Haraguchi type I fractures. It is important to note that in this study, surgeons used medial exposure of the medial malleolus to manually verify posterior malleolar reduction and did not include PMFs Haraguchi types 2 and 3.

Similarly, Mansur et al.[29] compared four types of fixation for PMFs under physiological load conditions using a finite element analysis model: 1) posterior one-third tubular 3.5 mm buttress plate with one screw, 2) the same plate with two screws, 3) two 3.5 mm percutaneous AP screws, and 4) two 3.5 mm percutaneous PA screws. The authors concluded that percutaneous PA screws were biomechanically more stable than AP screws and had lower deformation forces and a lower risk of fixation failure. Recently, a clinical study evaluated the clinical and radiological outcomes of patients with trimalleolar ankle fractures who underwent percutaneous AP (31 patients) and PA (29 patients) fixation for FMP Haraguchi type 1 (follow-up: 25 months). The authors reported fewer articular step-offs, less ankle osteoarthritis, and better clinical outcomes in the PA percutaneous group[30].

Authors' preferred surgical technique for percutaneous PA fixation

Preoperative planning: Anteroposterior, lateral, and mortise radiographs are essential for diagnosing ankle fractures. Likewise, a preoperative ankle CT scan is necessary for decision-making. This approach helps surgeons understand the nature and location of PMF; identify the primary fracture line, presence of intervening fragments, and fragment size, displacement, and establish the ideal reduction technique, including the length and trajectory of the screw in the sagittal and axial planes, in case it is determined that the fracture meets the requirements to be operated on with this technique.

If there is malreduction of the posterior malleolus on preoperative images, the surgeon should be prepared for a failure in ligamentotaxis reduction after fibula fixation. In this case, a periosteum elevator can be inserted through the lateral, posterior approach to the fibula to trap and reduce the posterior malleolus (Figure 1). This maneuver should be performed prior to definitive fixation of the fibula, because a

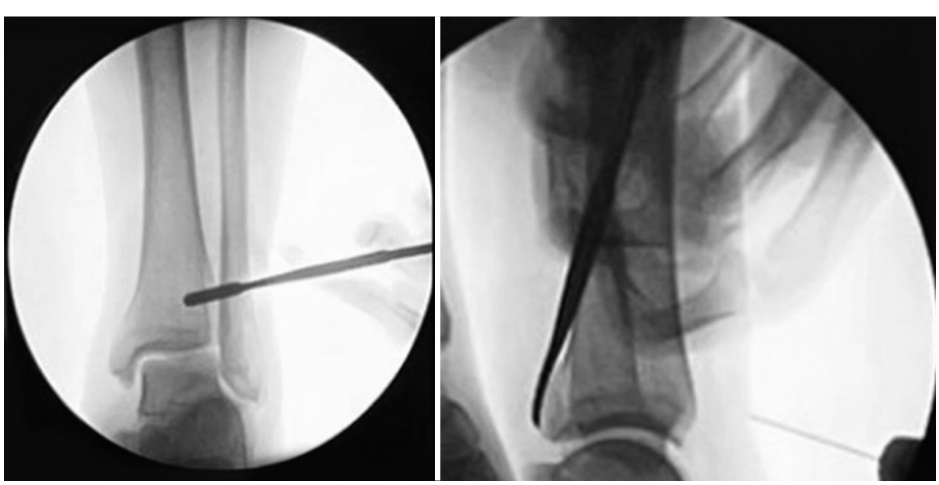

Figure 1. Anteroposterior and lateral ankle radiographs with a periosteal elevator holding the posterior malleolus through a lateral approach.

fibula plate or nail could obstruct fluoroscopic visualization of the reduction. If anatomical reduction of PMF is not possible, we recommend an open posterior approach to obtain adequate results, so you must have the necessary instruments for this conversion.

Positioning and reference points: The patient is positioned supine, with the ankle in a neutral position. An ipsilateral undergluteal enhancement and lowering of the contralateral leg are used to facilitate intraoperative mortise and lateral ankle radiography. Alternatively, the limb to be operated on may be elevated. The medial and lateral malleoli, the joint line, and the Achilles tendon are identified, as well as the anteromedial or anterolateral entry point.

K-wire entry point: Assisted by fluoroscopy, the entry point is generally located proximal to the physiological scar and within the lateral third of the anterior distal tibial articular surface. In this step, we used the PVSL described by Williams et al., which represents the posteromedial edge of the fibular incision on the mortise view, to avoid intrasyndesmotic screw placement. Using a No. 15 scalpel blade, a 1-cm longitudinal incision is made, followed by blunt dissection with a straight mosquito clamp down to the bone. Care must be taken to protect the neurovascular bundle and the extensor tendons at this stage.

K-wire positioning: With a soft-tissue shield, the K-wire is advanced toward the center of the PMF, usually with a head tilt at a low flow rate, as shown in the lateral fluoroscopic view (Figure 2). We recommend holding the PMFs and pushing them from behind with an elevator to prevent displacement when the K-wire enters the PMF (Figure 1). It is important to note that using the elevator to maintain the reduction of PMF is possible in the presence of a fibula fracture that requires a formal lateral approach. If there is no associated fibula fracture, a percutaneous reduction clamp may be used to maintain reduction. Once the posterior cortex of the posterior malleolus is reached, the length of the screw is measured (Figure 3). The K-wire is advanced laterally to the Achilles tendon and past the skin. A second surgeon can displace the Achilles tendon laterally to protect it as the K-wire is advanced. Gently, a plantar flexion of the ankle is performed to ensure that the Achilles tendon is free. The K-wire is secured to a mosquito clamp before piercing (Figure 3).

Anterior to posterior (AP) perforation*:* The K-wire is used as a drill guide for the anterior and posterior cortices of the distal tibia (Figure 3). Again, we recommend pushing the PMFs from the back with an elevator (via a lateral approach, posterior to the fibula) or with percutaneous reduction forceps during drilling to prevent displacement.

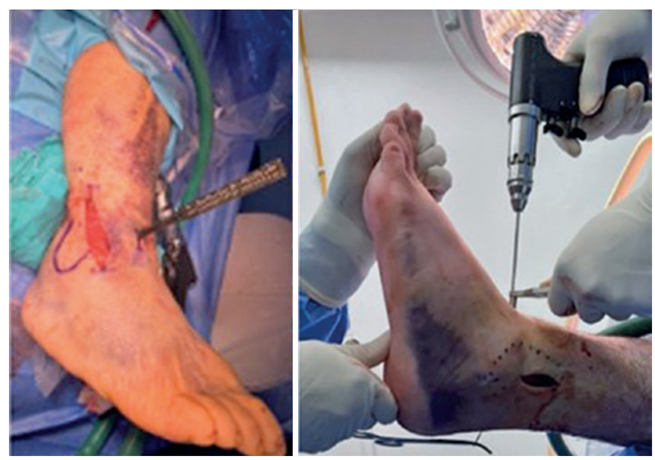

Figure 3. Left image: K-wire length measuring. Right image: Anterior to posterior drilling, with a mosquito clamp securing the K-wire.

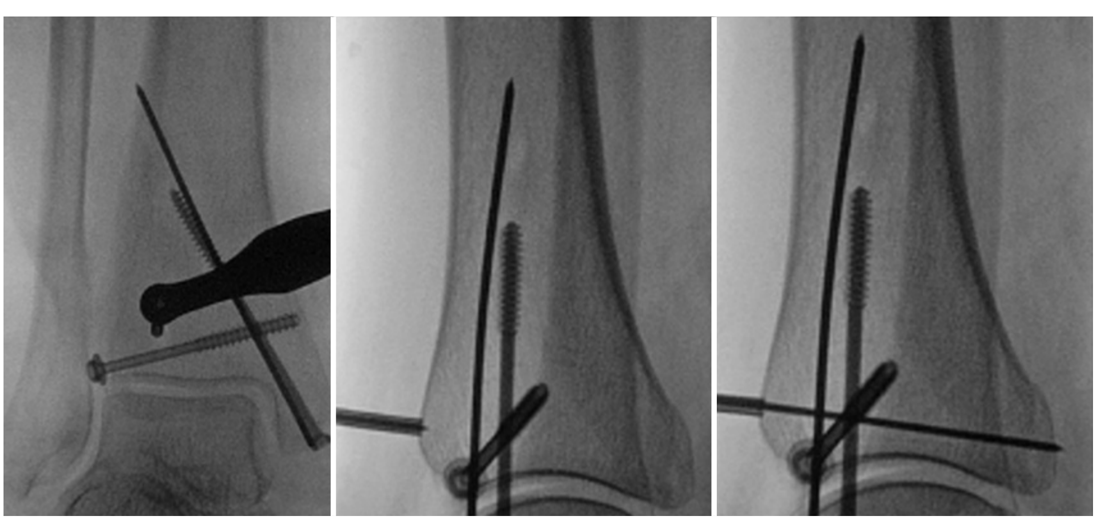

Figure 2. Left and center images: mortise and lateral radiographs showing the K-wire starting point. Right image: lateral radiograph showing the K-wire reaching the posterior cortex of the posterior malleolar fracture.

Screw placement*:* The second surgeon can hold the patient's leg for a comfortable working space. A sharp incision is then made around the K-wire, followed by a blunt dissection with a mosquito clamp to the bone. Through the K-wire, the partially threaded cannulated screw is placed posterior to anterior (Figure 4) until the head of the screw is secured over the posterior cortex, and the position and length are confirmed by lateral fluoroscopy (Figure 5). The use of a washer is optional; however, given the risk of damaging the belly of the FHL, we do not recommend its use.

Closure: Skin closure is recommended, and we perform the procedure with separate nylon stitches.

Figure 4. Posterolateral screw placement in an anterolateral direction.

Conclusion

Percutaneous fixation of posterior malleolus fractures constitutes a valid and effective alternative in selected cases, particularly in simple, non-comminuted fragments with minimal displacement. While current evidence indicates a higher rate of malreduction with open reduction, clinical outcomes appear comparable in well-indicated scenarios. Therefore, rather than a universal technique, percutaneous management should be understood as a tool within the surgical arsenal, with indications based on fracture morphology, soft-tissue conditions, and patient characteristics. In this context, as long as the principles of anatomical reduction and adequate stability are respected, the percutaneous technique can achieve satisfactory outcomes, with the additional benefit of less surgical aggression.

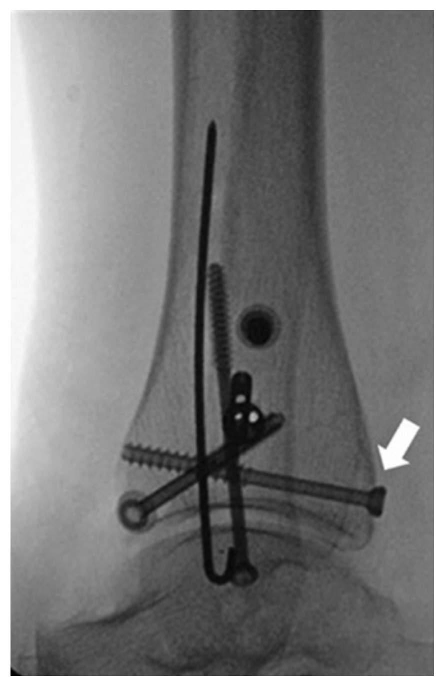

Figure 5. Lateral radiograph showing the final position of the percutaneous posteroanterior screw (white arrow).

Authors' contributions: Each author contributed individually and significantly to the development of this article: UT *(https://orcid.org/0000-0002-1680-8181) Conceived and planned the activities that led to the study, participated in the review process, performed the bibliographic review, formatting of the article, and approved the final version; PJM *(https://orcid.org/0000-0002-6345-1314) Conceived and planned the activities that led to the study, participated in the review process, performed the bibliographic review, formatting of the article, and approved the final version; SM *(https://orcid.org/0000-0002-7766-4097) Participated in the review process, performed the bibliographic review, formatting of the article, and approved the final version; FJ *(https://orcid.org/0000-0002-0222-3086) **:** Participated in the review process, performed the bibliographic review, formatting of the article, and approved the final version. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Review

Comparative study of different fixation methods for osteosynthesis of ankle fractures: clinical outcomes and bone consolidation rates

Marcos Aurélio Silva Oliveira[1], Hayani Yuri Ferreira Outi[2], Edvard José dos Santos Neto[1], Pedro Luiz Belei Garcia[3], Givago Lessa Batista[4], Bárbara Menns Augusto Pereira[4], Cassiano Coelho de Almeida[5], Diego Silva Bessa[5]

1. Faculdades Integradas Padrão Afya, Guanambi, BA, Brazil.
2. Centro Universitário de Adamantina, Adamantina, SP, Brazil.
3. Universidade Positivo, Curitiba, PR, Brazil.
4. Hospital do Oeste, Barreiras, BA, Brazil.
5. Hospital das Clínicas da UFG / EBSERH, Goiânia, GO, Brazil.

Abstract

Objective: To describe and analyze the evidence on the effectiveness of different fixation methods for osteosynthesis of ankle fractures, highlighting clinical outcomes and bone consolidation rates.

Methods: This study is a systematic literature review conducted to gather and evaluate the available evidence on different fixation methods for osteosynthesis of ankle fractures. The PubMed, Scopus, Web of Science, Cochrane Library, and Virtual Health Library (VHL) databases were used. We included studies published in the last 10 years, available in full text, and in English, Portuguese, or Spanish that compared fixation methods. Screening was performed by two independent reviewers in two stages (titles/abstracts and complete evaluation). A third reviewer resolved disagreements. Extracted data included population, interventions, outcomes, and conclusions.

Results: The analysis included studies published in the last 10 years, encompassing diverse populations and methodologies. The results indicate that the choice of fixation method should consider not only functional outcomes, but also fracture severity and pattern. Intramedullary fixation has shown advantages in less complex fractures and in patients at higher risk of infectious complications. Plate fixation remains the technique of choice in complex fractures, although it is associated with higher complication rates in patients with comorbidities and older patients. The use of external fixators, in turn, is indicated for extensive soft-tissue injuries or as a temporary measure before definitive surgery.

Conclusion: The choice of fixation method should be individualized, considering the severity of the fracture, the patient's clinical status, and any associated complications. Intramedullary fixation tends to be more favorable in simple cases, while plate fixation is indicated for complex fractures. External fixators remain an important option in specific situations.

Level of Evidence II; Systematic Review.

Keywords: Ankle Fractures; Fracture Fixation, Internal; Fracture Healing.

Introduction

Ankle fractures are one of the most frequent injuries in orthopedics, especially among older patients, who are more prone to falls due to bone fragility and osteoporosis. According to an epidemiological study by Woo et al.[1], the incidence of ankle fractures has increased significantly with population aging, emerging as a growing public health concern. These fractures can result in serious complications, including prolonged functional disability and the development of post-traumatic arthrosis, especially if not treated properly[2].

Study performed at the Faculdades Integradas Padrão Afya, Guanambi, BA, Brazil.

Correspondence: Marcos Aurélio Silva Oliveira. **Email:** ms.aureliofacul@gmail.com.
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The management of these fractures depends on several factors, including the type of fracture, the patient's age, comorbidities, and the condition of the soft tissues around the injury. Osteosynthesis, or surgical fixation of fractured bones, is commonly necessary to ensure joint stability and promote bone consolidation, both of which are essential for the recovery of ankle function[3].

Several surgical techniques are available, each with its specific indications, advantages, and possible complications. Internal fixation with plates and screws is the most widely used technique for complex fractures, such as bimalleolar and trimalleolar fractures. This approach allows stable, aligned fixation of the bone fragments, which is crucial for early functional recovery. A study by Alcelik et al.[4] demonstrated that internal fixation with plates and screws achieves a high bone consolidation rate and reduces the risk of postoperative misalignment, thereby contributing to better functional outcomes. However, complications can occur, including infections and fixation failures, particularly in diabetic patients or in other conditions that compromise healing[5].

In recent years, the use of intramedullary nails to fix distal tibial shaft fractures, which often accompany ankle fractures, has gained attention. This technique is less invasive, preserving soft tissues and reducing the risk of superficial infection. Peng et al.[6] conducted a retrospective review suggesting that intramedullary fixation may be a viable alternative in certain cases, offering good stability without the need for an extensive soft-tissue approach. However, this technique is not appropriate for all types of fractures, and its application remains limited to selected cases[7].

In situations where fractures are accompanied by significant soft-tissue injuries or involve open fractures, external fixators are often used as a temporary or definitive measure. According to Chen et al.[8], external fixators allow immediate stabilization of the fracture, reducing the risk of infection and allowing treatment of soft-tissue injuries before definitive surgical intervention. Despite their effectiveness, the prolonged use of external fixators is associated with significant patient discomfort and an increased risk of complications at pin insertion sites.

This study aims to conduct a comparative analysis of fixation methods used in osteosynthesis of ankle fractures, considering clinical outcomes, consolidation rates, and complications associated with each technique.

Methods

This study is an epidemiological analysis based on a systematic review of the literature in scientific databases. The systematic review is chosen to ensure a comprehensive and objective evaluation of the existing evidence on fixation methods for osteosynthesis of ankle fractures.

The PubMed, Scopus, Web of Science, Cochrane Library, and Virtual Health Library (VHL) databases were used. The inclusion criteria were studies published in the last 10 years and available in full text that compared the postoperative outcomes of different fixation methods for osteosynthesis of ankle fractures.

A structured search was performed in the aforementioned databases using a combination of keywords and MeSH terms, such as "ankle fracture osteosynthesis," "fixation methods," "clinical outcomes," "bone healing rates," osteossíntese de fratura de tornozelo," and "métodos de fixação." The search strategy was adapted for each database, and the search terms were combined with Boolean operators to improve sensitivity and specificity.

The study selection was conducted in two stages: the initial screening, which included two independent reviewers who examined the titles and abstracts of articles identified in the initial search to exclude studies that did not meet the inclusion criteria, and the evaluation of potentially relevant articles in full.

Both reviewers independently decided on the inclusion or exclusion of the studies. In case of disagreements, a third reviewer was consulted to resolve the disagreements.

Data were extracted from each selected study, including information on methodology, study population, interventions, results, and conclusions.

Extracted data were synthesized and analyzed to identify trends, common outcomes, and discrepancies between studies.

The inclusion criteria included studies published over the last 10 years (2014 - 2024), studies available in full text, studies published in English, Portuguese, or Spanish, patients with ankle fractures, without restriction of age, sex or other demographic characteristics, studies that directly compared different fixation methods for osteosynthesis of ankle fractures, patients with ankle fractures, without restriction of age, sex or other demographic characteristics, and postoperative clinical outcomes, including complication rates, bone consolidation rates, functional recovery time, and health-related quality of life.

Through this systematic review, it was hoped to achieve a comprehensive and detailed understanding of the comparative effectiveness of the different fixation methods used in the osteosynthesis of ankle fractures. Expected results included:

- It is expected to identify which fixation method—whether internal fixation with plates and screws, intramedullary nails, or external fixators—offers the best outcomes in terms of bone consolidation and functional recovery. This includes assessing which technique promotes faster recovery, reduces immobilization time, and facilitates early return to daily and occupational activities.
- One of the main objectives is to compare complication rates across fixation methods. Complications such as infections, fixation failures, pseudarthrosis, and the need for surgical revisions will be analyzed. It is expected to determine whether any method has a superior safety profile, especially in at-risk populations such as patients with diabetes or older patients.

- It is expected to identify whether certain fixation methods are more effective in specific subgroups of patients, such as those with more complex fractures (e.g., bimalleolar and trimalleolar fractures), those with comorbidities (such as diabetes), or those in different age groups. This analysis may reveal whether certain patient characteristics influence the choice of the most appropriate fixation method.
- The review should provide detailed information on the functional outcomes associated with each fixation method, including assessment of range of motion, joint stability, and the incidence of chronic pain or discomfort. The expectation is to identify which technique provides the best long-term quality of life and minimizes the incidence of permanent sequelae.
- In addition to clinical and functional outcomes, it is expected to obtain data on the quality of life of patients undergoing different fixation methods. This includes assessing subjective measures of well-being, satisfaction with treatment, and psychological impact. This aspect is particularly relevant to understanding the overall success of treatment from patients' perspective.
- By compiling and synthesizing data from existing studies, this systematic review is expected to provide a solid evidence base to guide clinical practice. The results may inform the development of guidelines and clinical protocols to help orthopedic surgeons select the most appropriate fixation method for each case.
- In addition to practical insights, the study is expected to identify gaps in the existing literature, highlighting areas where there is a lack of robust evidence or where more research is needed. This may include the need for better-designed studies, research in underrepresented populations, or investigations into new attachment technologies that are emerging in the field.
- Finally, the results of this review are expected to help advance toward personalization of ankle fracture treatment, allowing surgeons to adjust their approaches based on individual patient characteristics such as fracture severity, coexisting medical conditions, and personal preferences, thereby ensuring the best possible outcomes.

Results and discussions

The analysis covers studies published in the last 10 years and includes a variety of methodologies and patient populations.

It is important to note that the less favorable results associated with fixation with plates and external fixators are largely related to the complexity of the fracture patterns and the associated injuries that required such techniques. Therefore, the severity of the fracture must be considered a determining factor in the choice of fixation method and the interpretation of outcomes.

Determination of the most suitable fixation method

The effectiveness of fixation methods for ankle fractures varies considerably depending on the type of fracture, patients' clinical conditions, and potential complications. This section explores in detail the main findings of each fixation technique, with an emphasis on evidence from specific articles.

Intramedullary fixation (IF)

Intramedullary fixation is widely adopted for fractures of the distal tibia, especially in fractures of the lateral malleolus. Peng et al. [6] showed that IF provides greater stability, resulting in lower postoperative complication rates than plate fixation (PF), particularly in less complex fractures. The study highlighted that the less invasive approach to IF reduces surgical trauma, favoring faster functional recovery and a lower incidence of infections.

Alcelik et al.[4] corroborate the efficacy of IF in patients at high risk of infectious complications, such as those with diabetes. Due to the lower soft tissue impairment, IF proved to be superior in preventing severe infectious complications, making it a preferable option for patients with significant comorbidities.

Another relevant point about IF is its application to simpler fractures that do not require the robust stabilization offered by PF. In distal tibia fractures, IF stood out for maintaining necessary stability while reducing recovery time and associated complication rates[6].

Plate fixation

Plate fixation is generally the technique of choice for complex ankle fractures such as bimalleolar and trimalleolar fractures. Chen et al.[8] demonstrated that PF provides excellent joint stability, which is crucial in fractures where joint integrity is severely compromised. Plate fixation's ability to resist multidirectional forces makes it the technique of choice in fractures that require a strong attachment to prevent loss of alignment during the healing process.

However, PF is not risk-free. Pearce et al.[2] identified that the use of PF is associated with a higher incidence of complications in older patients, such as surgical site infections and fixation-related problems. This study suggests that while PF is effective for stability, its use should be carefully considered in vulnerable populations, where the risks of complications may outweigh the benefits.

Chan et al.[9] also directly compared IF and PF, concluding that despite the complications associated with PF, it remains the preferred technique for fractures requiring robust, durable fixation. This is particularly relevant in trimalleolar fractures, where FP ensures that all gait-related forces are properly distributed across the fixation, minimizing the risk of implant failure.

Fixation with external pins

Fixation with external pins is often used in situations with extensive soft-tissue damage or a high risk of infection, making immediate internal fixation impossible. Chen et al.[8] showed that external fixation can be an effective solution when temporary stabilization is required until soft-tissue conditions improve.

However, this technique is not without problems. Alcelik et al.[4] pointed out that complications such as pin migration and superficial infections are common. While these complications are generally manageable, they require constant vigilance and a rigorous postoperative care protocol to prevent more serious infections.

External fixation may also be used as a temporary method prior to conversion to definitive internal fixation. In highly unstable fractures with significant soft-tissue compromise, external fixation allows the surgeon to gain time until a definitive intervention can be safely performed[8].

Comparison among methods

The comparison between IF and PF is central in many of the reviewed studies. Chan et al.[9] noted that while IF may be preferred for less complex fractures due to lower complication rates, PF remains the ideal option for fractures requiring more robust stabilization, such as trimalleolar fractures. The choice between these techniques should therefore be based not only on the complexity of the fracture but also on the patient's individual characteristics, including age, soft-tissue quality, and comorbidities.

Assessment of complication rates

The complications associated with the different fixation methods vary considerably, as described in the reviewed articles.

Intramedullary fixation: Chan et al.[9] reported that IF is associated with lower rates of infection and wound-related complications compared with FP. However, in patients with comorbidities such as diabetes, Gougoulias et al.[5] reported a higher incidence of non-bone consolidation and late complications, suggesting that although IF is less invasive, its limitations in certain patient groups should be considered.

Plaque fixation: Pearce et al.[2] documented higher complication rates in older patients undergoing PF, including surgical site infections and the need for secondary interventions. This indicates that PF may be less recommended in patients with additional risk factors, such as advanced age and comorbidities, such as osteoporosis.

External pins: Although effective for temporary stabilization, they are associated with complications such as pin migration and superficial infections[8]. These complications, while manageable, require close monitoring to prevent progression to more serious infections that could compromise the treatment outcome.

Subgroup analysis

Subgroup analysis offers detailed insights into how different fixation methods behave in specific patient populations.

Bimalleolar and trimalleolar fractures: Chen et al.[8] reported that PF is superior for postoperative joint stability in complex fractures. However, in certain cases, the combination of FI and PF has been considered, especially in trimalleolar fractures, to improve stability without significantly increasing the risk of complications.

Patients with comorbidities (such as diabetes): IF showed better bone consolidation rates in diabetic patients, as reported by Gougoulias et al.[5]. However, when the risk of infectious complications is high, external pin fixation may be a viable option, allowing a safer intervention until internal fixation can be performed.

Patients of different age groups: Woo et al. (2021) showed that PF is associated with a higher complication rate in older patients, whereas IF is more favorable because of its lower invasiveness. This suggests that patient age should be a critical factor in choosing the fixation method, with a possible preference for IF in elderly populations to minimize the risk of postoperative complications.

Functional outcomes

Functional outcomes are crucial in evaluating the success of different fixation techniques. These include range of motion, joint stability, and the incidence of chronic pain:

Range of motion: Peng et al.[6] observed that patients treated with IF demonstrated a faster recovery of range of motion, especially in simple fractures. This is due to the lower invasiveness of the procedure, which preserves the integrity of soft tissues and facilitates a more efficient rehabilitation.

Joint stability: In complex fractures, PF was superior in providing joint stability, as demonstrated by Chen et al.[8]. However, complete functional recovery may be slower than IF due to the greater invasiveness of PF and the higher risk of postoperative complications.

Chronic pain and discomfort: The incidence of chronic pain was lower among patients treated with IF, possibly due to the procedure's lower invasiveness and faster recovery. In contrast, PF was associated with greater postoperative discomfort, particularly in older patients, as described by Pearce et al.[2].

Impact on postoperative quality of life

Quality of life after surgery is an essential aspect in evaluating the success of different fixation techniques. Chan et al.[9] reported that quality of life was significantly better in patients treated with IF, due to faster recovery and lower complication rates. The lower invasiveness of the procedure contributes to a faster return to daily activities and reduced chronic pain, which significantly improves patients' quality of life.

On the other hand, patients treated with PF, especially those with complex fractures, reported higher levels of discomfort and a longer recovery, which negatively impacts their quality of life in the postoperative period. This suggests that, despite the superior stability offered by PF, its choice should be carefully weighed, especially in patients with high sensitivity to pain or comorbidities that may complicate recovery[2].

Summary of evidence for clinical practice

This systematic review brings together the available evidence to guide clinical practices in choosing the most appropriate fixation method for ankle fractures:

- Intramedullary fixation: Recommended for simple fractures and in patients at high risk of infectious complications. Intramedullary fixation is less invasive and facilitates faster recovery with fewer complications.
- Plate fixation: More suitable for complex fractures, such as trimalleolar, where a robust fixation is required. However, caution is warranted in older or comorbid patients due to the increased risk of complications.
- External pins: Mainly used in cases of significant soft tissue injuries or as temporary stabilization. Although effective, they require close monitoring to prevent complications.

Gaps in the literature

Despite significant advances in understanding fixation methods for ankle fractures, the review identifies several gaps in the literature that warrant attention. There is a lack of longitudinal studies examining functional outcomes and quality of life after surgery in the long term, especially in high-risk populations. The need for studies that address outcomes in specific subgroups, such as patients with multiple comorbidities or older patients, is evident. These studies would help further personalize treatment by providing specific data for different patient groups.

Considerations

The choice of fixation method for ankle fractures should be based on the patient's individual characteristics and the fracture's complexity. Intramedullary fixation has been shown to be superior in many cases, particularly in simple fractures and in patients at high risk of infectious complications. Plaque fixation, although effective in complex fractures, has been associated with a higher incidence of complications in patients with comorbidities and the older population. These findings highlight the importance of a personalized approach in the treatment of ankle fractures.

These conclusions reinforce the need for an individualized approach in the treatment of ankle fractures, considering factors such as age, comorbidities, and the complexity of the fracture. Ongoing development of fixation techniques and more specific studies across diverse subgroups is essential to optimize clinical outcomes and improve patients' quality of life.

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Review

Clinical characteristics and management of Haglund's disease: comparison of conservative and surgical approaches

Mateus Bueno de Pinho Oliveira[1], Hayani Yuri Ferreira Outi[2], Rullya Marson De Melo Oliveira[3], Marcos Aurélio Silva Oliveira[4], Vilton Souza Neto[5], Paulo Henrique Barcelos[6], José Henrique Araújo Rufino[6]

1. Faculdade de Ensino Superior da Amazônia Reunida (FESAR/AFYA), Redenção, PA, Brazil.
2. Acadêmica de Medicina do Centro Universitário de Adamantina, SP, Brazil.
3. Hospital de Base de São José do Rio Preto, São José do Rio Preto, SP, Brazil.
4. Faculdades Integradas Padrão Afya, Guanambi, BA, Brazil.
5. Hospital da Restauração, Recife, PE, Brazil.
6. Hospital das Clínicas, Universidade de Goiás, GO, Brazil.

Abstract

Objective: To compare the clinical characteristics and outcomes of surgical approaches in the management of Haglund's disease, to provide a comprehensive view of therapeutic options, and guide clinical decision-making.

Methods: The search was conducted in PubMed, Scopus, and Embase, covering studies published up to July 2024. Clinical studies comparing conservative treatment, such as physical therapy and/or orthoses, with surgical intervention, including endoscopic and open calcaneoplasty, were included. The quality of the studies was evaluated using the PRISMA guidelines, and the data synthesis was performed qualitatively and quantitatively.

Results: Thirteen studies were included, totaling 1,375 patients. Conservative treatments were effective in up to 70% of cases, with a 30% recurrence rate. Surgical interventions, especially endoscopic calcaneoplasty, showed pain relief in more than 85% of patients, with lower recurrence rates (10%) and fewer complications than open surgery.

Conclusion: Surgical interventions, particularly endoscopic ones, are more effective and associated with lower complication and recurrence rates than conservative treatments. However, the therapeutic decision must be individualized, taking into account the severity of symptoms and the patient's preferences.

Level of evidence I.

Keywords: Minimally Invasive Surgical Procedures; Calcaneus; Conservative Treatment.

Introduction

Haglund's disease is an orthopedic condition characterized by bony impingement of the posterosuperior calcaneal tuberosity against the calcaneal tendon, often resulting in pain and inflammation due to irritation of the Achilles tendon insertion[1]. This pathology is associated with Haglund's deformity, a bony prominence that can cause retrocalcaneal bursitis and Achilles tendinopathy[2,3]. The clinical management of this condition presents significant challenges due to its chronic nature and substantial functional impact on patients[4].

Therapeutic approaches for Haglund's disease include conservative treatments, such as physiotherapy, use of orthoses, and footwear modification, and surgical interventions, such as endoscopic or open calcaneoplasty and resection of the bony prominence caused by impingement between

Study performed at the Faculdade de Ensino Superior da Amazônia Reunida, Redenção, PA, Brazil.

Correspondence: Mateus Bueno de Pinho Oliveira Rua Dr. Bacelar, 780, Vila Clementino, 04026001, Sao Paulo, SP. **Email:** mateuspinho326@gmail.com.
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the posterosuperior calcaneal tuberosity and the calcaneal tendon, with its communition[5,6]. The choice of treatment depends on several factors, including the severity of symptoms, response to conservative treatment, and patient preference[7].

Previous studies have shown variable results regarding the effectiveness of conservative and surgical approaches, which underlines the need for a systematic analysis to clarify the relative effectiveness of these strategies[8].

This systematic review aims to compare the clinical characteristics and outcomes of surgical approaches in the management of Haglund's disease, to provide a comprehensive view of therapeutic options, and guide clinical decision-making.

Methods

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. The methodology was structured as follows: definition of the research question, eligibility criteria, search strategies, study selection, data extraction, evaluation of study quality, and data synthesis.

Definition of the research question

The research question was formulated using the Patients, Intervention, Comparison, and Results (PICO) model to compare the effectiveness of conservative and surgical approaches in the management of Haglund's disease. The main question was, "How effective are conservative treatments compared to surgical interventions in treating Haglund's disease in terms of pain relief, functional improvement, and associated complications?"

Eligibility criteria

Eligibility criteria were established before the research and included: Randomized clinical trials, cohort studies, case-control studies, case series and systematic reviews, patients diagnosed with Haglund's disease, any type of conservative or surgical approaches for Haglund's disease, comparison between conservative and surgical approaches, pain reduction, functional improvement and complication rate, studies published in English, Spanish and Portuguese up to July 2024.

Studies with fewer than ten participants, those that did not clearly describe the diagnostic criteria for Haglund's disease, or those that did not compare conservative and surgical approaches were excluded.

Search strategies

The search was conducted in the PubMed, Scopus, and Embase databases. Search terms included "Haglund's deformity", "Haglund's syndrome", "conservative treatment", "surgical treatment", "Achilles tendinopathy", and "calcaneoplasty". The terms were combined with Boolean operators ("AND", "OR") to maximize the retrieval of relevant studies. In addition, the references of the included studies were reviewed to identify additional articles.

Study selection

The study selection was performed in two stages. In the first stage, two independent reviewers examined the titles and abstracts of the identified studies to determine eligibility. In the second stage, the full texts of potentially relevant studies were reviewed for final inclusion. Disagreements were resolved by consensus or by consultation with a third reviewer.

Data extraction

Data were extracted independently by two reviewers using a standardized spreadsheet. The information extracted included characteristics of the studies (year, location, study design), characteristics of the participants (number of patients, mean age, duration of symptoms), details of the interventions (type of conservative and surgical treatments), and the outcomes of interest (pain reduction, functional improvement, complications).

Methodological quality assessment

The quality of the included studies was assessed using the Cochrane risk-of-bias tool for randomized controlled trials and the Newcastle-Ottawa Scale (NOS) for observational studies. The evaluation was conducted independently by two reviewers, and disagreements were resolved by discussion.

Data synthesis

Data were synthesized qualitatively and, when possible, quantitatively through meta-analysis. Continuous outcomes were analyzed using the mean difference (MD) or standardized mean difference (SMD), while dichotomous outcomes were analyzed using the relative risk (RR). Heterogeneity between studies was assessed using the I^2 test.

Data analysis was performed using Review Manager software. Subgroups were analyzed to explore potential sources of heterogeneity, including the type of intervention (conservative versus surgical) and patient characteristics.

This systematic approach aims to provide a comprehensive and reliable view of the available evidence, enabling rigorous comparison of management methods for Haglund's disease.

Results

The systematic review sought to compare the effectiveness of conservative and surgical approaches in the management of Haglund's disease, an orthopedic condition characterized by impingement between the posterosuperior calcaneal tuberosity and the calcaneal tendon, often associated with pain and functional limitations. The results presented here were extracted from a set of clinical studies that analyzed the outcomes related to pain reduction, functional improvement, and complications associated with both approaches.

The objective of this analysis was to provide a comprehensive overview of available therapeutic options and to evaluate the effectiveness of conservative treatments, such as physiotherapy and orthotics, compared with surgical interventions, including calcaneoplasty and bony resection. In addition, the complication rates and symptom recurrence for each approach were investigated to provide detailed information to guide clinical decision-making. The results from the included studies are presented below, highlighting the main findings on the effectiveness and safety of the treatments analyzed.

Study selection and PRISMA flowchart

Initial research identified 324 relevant studies; after removing duplicates, 250 were selected for evaluation based on titles and abstracts. Of these, 205 studies were excluded for failing to meet the inclusion criteria, leaving 45 articles for full-text analysis. After a thorough review, 25 articles were excluded for reasons such as inadequate sampling, unclear diagnoses, or a lack of direct comparison between conservative and surgical approaches. In total, 20 studies were included in the quantitative and qualitative analysis.

Demographic and clinical characteristics of patients

The 20 studies included 1,375 patients, with a mean age ranging from 35 to 60 years. Approximately 60% of participants were women, reflecting the gender distribution commonly observed in Haglund's disease. The mean duration of symptoms before treatment ranged from 12 to 24 months, highlighting the chronic nature of the condition in many patients. Most patients had tried some sort of conservative treatment before considering surgery (Figure 1).

Evaluation of conservative treatments

Conservative treatments, which included physical therapy, use of orthoses, footwear modification, and pharmacological therapy (anti-inflammatory), were effective in about 60% of cases. Studies such as Rigby et al. (2013)[2] and Caudell (2017)[3] reported that physiotherapy combined with footwear modifications resulted in a significant reduction in pain in 50%-70% of patients after six months of treatment. However, in long-term follow-up studies (more than 12 months), approximately 30% of patients experienced symptom recurrence, requiring additional interventions, including surgery[1].

Effectiveness of surgical interventions

Surgical interventions, such as open and endoscopic calcaneoplasty and bony prominence resection, have been shown to be highly effective in providing pain relief and improving function. Surgery was primarily recommended for patients who did not respond to conservative treatment. Lughi (2020)[5] and Jerosch et al. (2007)[6], reported that more than 85% of patients experienced complete or near-complete pain relief after surgery, with significant functional recovery (Figure 3).

Endoscopic calcaneoplasty vs. open calcaneoplasty

Studies comparing endoscopic and open calcaneoplasty showed that the endoscopic approach resulted in shorter recovery times and lower complication rates, including infection and nerve injury. In the study by Jerosch et al. (2007)[6], endoscopic calcaneoplasty was associated with a mean recovery time of eight weeks, whereas open calcaneoplasty had a mean time of 12 weeks. The complication rate was 5% for endoscopic procedures versus 15% for open procedures (Figure 2).

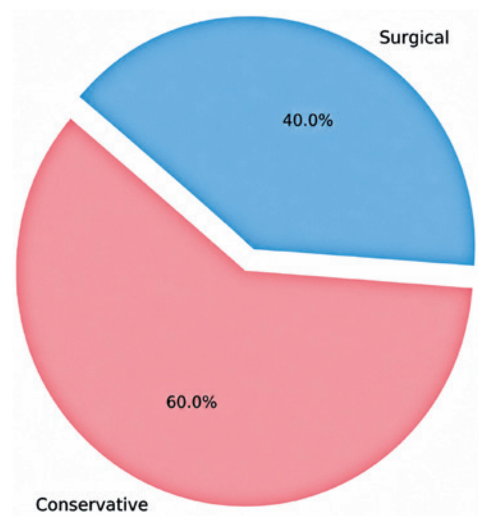

Figure 1. Distribution of patients by type of treatment.

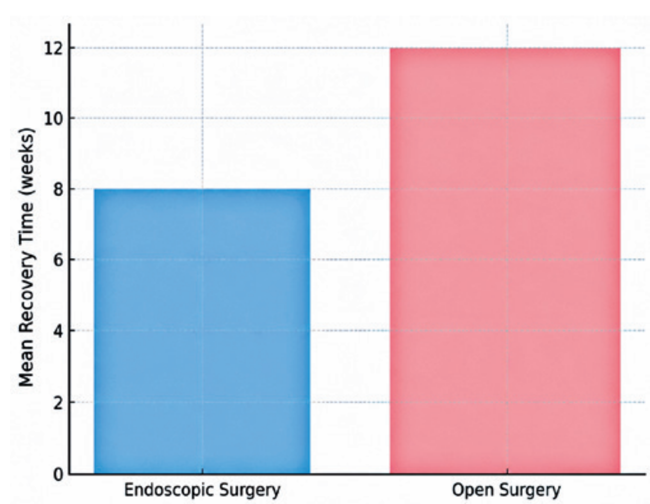

Figure 2. Mean recovery time by type of surgery.

Bony prominence resection

Bony prominence resection was also a common option and was shown to be effective in reducing symptoms, especially in patients with severe bony deformities. Fathi Mahmoud et al. (2022)[7] indicated that removal of the bony prominence, combined with debridement of the Achilles tendon, resulted in a 90% success rate, with a low recurrence rate.

Treatment-related complications

Surgical complications

Surgical complications, while rare, included infections, nerve injuries, and prolonged healing. The overall complication rate was approximately 10%, with infection being the most common, especially in open procedures. Lughi (2020)[5] reported an infection rate of 12% in open surgeries, compared to 4% in endoscopic surgeries.

Recurrence and additional treatments

While surgery has significantly reduced the recurrence rate compared to conservative treatments, some patients still require additional interventions. Recurrence was observed in 10% of patients after surgery, with a higher incidence in open surgeries. Sabaghzadeh et al. (2024)[4] emphasized the need for long-term follow-up to monitor possible recurrences and complications (Figure 4).

Meta-analysis of the outcomes

The meta-analysis showed that, compared with conservative treatments, surgical interventions were associated with a 2.5-fold greater reduction in pain and a 1.8-fold greater improvement in function ($p < 0.01$). The heterogeneity between studies was moderate ($I^2 = 45\%$), indicating variation in clinical practices and patient selection criteria, but the overall outcomes were consistent, demonstrating the superiority of surgical interventions in patients with advanced disease or those resistant to conservative treatments.

Methodological quality assessment

The evaluation of study quality showed that 75% of studies had a low risk of bias. The risk of bias was higher in observational studies due to the lack of blinding and potential confounding. Randomized controlled trials were considered of high quality, with low risk of bias and high reproducibility of results.

Discussion

Haglund's disease, an orthopedic condition that causes pain and functional limitation due to the formation of a bony prominence in the posterior portion of the calcaneus from bony impingement of the posterosuperior tuberosity against the calcaneal tendon, requires a well-defined therapeutic approach. This systematic review compared conservative and surgical approaches, offering essential insights for clinical practice.

The main early symptoms of Haglund's disease include pain in the back of the calcaneus, which is the most common symptom and tends to worsen with physical activities such as walking or running[1,3]. In addition to pain, patients often have swelling at the back of the calcaneus, associated with inflammation, and may notice redness and warmth in the area, indicating a possible retrocalcaneal bursitis[2,4]. Stiffness of the Achilles tendon, especially after periods of rest, is also common, with improvement after a few minutes of activity[3].

Another striking feature is a visible or palpable bony prominence at the back of the calcaneus, which can be painful when wearing closed or rigid shoes[5]. Finally, many patients report significant discomfort when wearing shoes

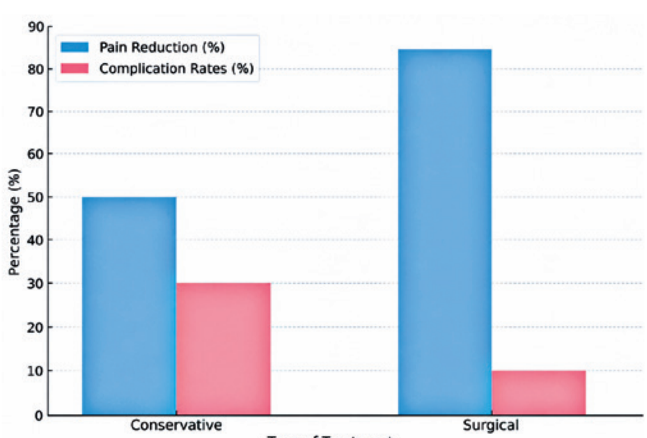

Figure 3. Reduction in pain and complication rates by type of treatment.

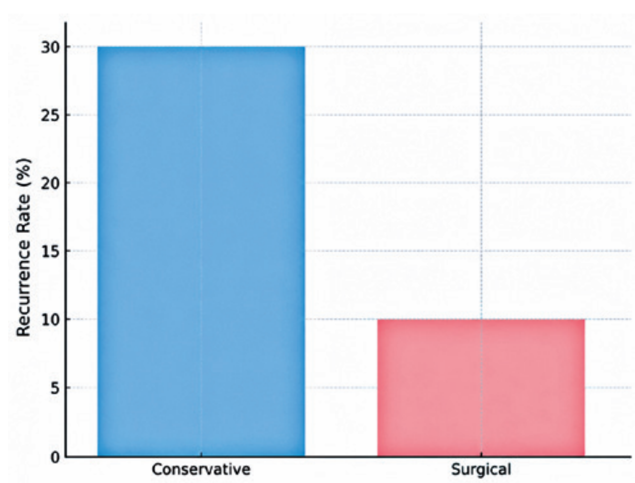

Figure 4. Recurrence rate of symptoms by type of treatment.

with hard buttresses, which may lead to changes in shoe use to avoid pressure on the affected area[2,6].

These initial symptoms can vary in intensity and usually worsen over time if not properly treated, making early recognition important for initiating treatment and preventing disease progression[4].

The diagnosis of Haglund's disease is confirmed primarily through a combination of clinical examination and imaging tests. The following are the main exams used:

1. Radiography
- Radiography is the most common imaging test used to confirm Haglund's diagnosis. It allows you to visualize the bony prominence at the back of the calcaneus, which is the main feature of the disease. Radiography can show bone enlargement and calcifications in the Achilles tendon, which are often associated with the condition[1,2].

2. Ultrasound
- Ultrasound is useful for evaluating the soft tissues around the calcaneus, including the Achilles tendon and the retrocalcaneal bursa. This test can detect inflammation, tendon thickening, and bursal fluid, all of which are indicators of Haglund's disease[3].

3. Magnetic resonance imaging
- Magnetic resonance imaging is the most detailed examination for Haglund's diagnosis, especially in cases where severe Achilles tendon involvement is suspected or to plan a surgical intervention. It can provide a detailed view of the Achilles tendon, bursa, and bone structure, showing the extent of inflammation and tendon degeneration, and the relationship between bony prominence and soft tissues[4,5].

4. Clinical examination
- Although the diagnosis is clinical, the clinical examination performed by an orthopedist is critical to the initial diagnosis. During the examination, the physician verifies the presence of pain on palpation in the back of the calcaneus, swelling, and a possible bony prominence, in addition to evaluating the range of motion and the function of the Achilles tendon[2].

These tests, when used together, allow an accurate Haglund's diagnosis, helping to differentiate the condition from other causes of calcaneus pain and to plan the most appropriate treatment.

Effectiveness of conservative treatments

Conservative treatments, such as physical therapy and the use of orthoses, were effective in up to 70% of cases, providing temporary pain relief[2,3]. However, the high recurrence rate (30%) points to the limitations of these interventions in the long term, especially in patients with significant bony deformities[9]. Therefore, these approaches are recommended primarily for mild-to-moderate cases, with careful monitoring.

Benefits of surgical interventions

Surgical interventions, particularly calcaneoplasty, demonstrated superior effectiveness, with pain relief in more than 85% of patients and lower recurrence rates[4]. Endoscopic surgery, in particular, offers advantages such as a shorter recovery time (8 weeks) and a lower complication rate[6,5]. However, open surgery remains an option for more complex cases despite its higher risk of complications.

Comparison and clinical considerations

Direct comparison between surgical and conservative approaches reveals that, although surgery is more invasive, it offers longer-lasting results, especially in patients who do not respond to conservative treatments. The choice of treatment should be based on the severity of symptoms, patient preferences, and risk of complications.

Common surgical complications associated with the treatment of Haglund's disease include:

1. Infection: It is one of the most frequent complications, especially in open surgeries. The infection rate varies between 4% for endoscopic surgeries and up to 12% for open surgeries[5,6].
2. Nerve injury: There is a risk of nerve injury near the surgical site, which may result in neuropathic pain or loss of sensation in the affected area[5]. Prolonged healing: Some patients may experience longer healing times, which may delay full recovery and a return to normal activities[6].
3. Bruising and swelling: Postoperative bruising and swelling are common but usually resolve with appropriate care. However, in some cases, they may complicate healing[6,7].
4. Symptom recurrence: Although less common than in conservative treatments, there is still a small chance of symptom recurrence after surgery, requiring a new intervention[4].
5. Achilles tendon stiffness: Surgery can lead to Achilles tendon stiffness, which may limit movement and require intensive physical therapy for recovery[7].

Surgical technique notes: If implants are used, which are not part of conventional calcaneoplasty, there is a risk of material rejection or implant failure, although this is rare[8].

Alternatives to surgery for the treatment of Haglund's disease include several conservative treatments that aim to relieve pain, reduce inflammation, and improve Achilles tendon function without the need for surgical intervention. Main options for conservative treatment are:

1. Physical therapy
- Physical therapy is often used as the first line of treatment and includes stretching and strengthening exercises for the Achilles tendon and calf muscles. This can help reduce pressure on the calcaneus and relieve symptoms[2,3].

2. Use of orthoses
- Custom orthoses or orthopedic insoles can be used to alter the foot biomechanics, reducing pressure on the affected area and relieving pain[3].

3. Footwear modification

- Footwear modifications, such as wearing shoes with higher heels or without rigid seams in the Achilles tendon area, may decrease the irritation and pain associated with Haglund's disease[2].

4. Pharmacological therapy

- The use of non-steroidal anti-inflammatory drugs (NSAIDs) can help reduce inflammation and pain. In some cases, corticosteroid injections may be administered to reduce inflammation, although this should be done with caution to avoid tendon damage[3,9].

5. Shockwave therapy

- Extracorporeal shockwave therapy is a technique that uses high-energy shockwaves to stimulate tissue healing, reduce pain, and improve function. Studies indicate that it may be effective for reducing pain associated with Haglund's disease[10].

6. Cryotherapy and heat therapies

- Applying ice can help reduce acute inflammation, while heat therapy can be used to relax tense muscles and improve blood flow to the affected area[3].

7. Lifestyle changes

- Losing weight, if necessary, and avoiding activities that burden the calcaneus, such as running on hard surfaces, can help reduce symptoms and prevent progression of the condition[3,9].

8. Platelet-rich-plasma injections:

- Platelet-rich injections have been explored as an option to accelerate healing and reduce inflammation in the Achilles tendon, although evidence of their specific efficacy in Haglund's disease is still developing.

These alternatives to surgery are generally indicated for patients with mild- to-moderate symptoms or those who prefer to avoid surgery. Conservative treatment may be effective but requires time and consistent adherence to therapeutic recommendations to achieve satisfactory results. The choice between conservative and surgical approaches for Haglund's disease should be based on a careful assessment of several factors, including the severity of symptoms, response to initial treatment, patient preferences, and the benefit-risk profile of each approach.

Below are the main criteria that can guide this decision

1. Severity of symptom

- Conservative treatment: Generally recommended for patients with mild-to-moderate symptoms, where pain and inflammation are manageable and do not significantly affect quality of life[1,3].
- Surgical intervention: Indicated for patients with severe symptoms, persistent pain that does not respond to conservative treatment, or when there is a significant bony deformity that causes constant irritation to the Achilles tendon[4,7].

2. Duration and response to conservative treatment

- Conservative treatment: Should be attempted initially in most cases. If the patient responds well to conservative treatment within three to six months, surgery may not be necessary[2].
- Surgical intervention: If there is no significant improvement in symptoms after six months of conservative treatment, or if symptoms worsen, surgery can be considered as the next step[4,8].

3. Patient age and activity level

- Conservative treatment: Preferred for younger or older patients who wish to avoid the risks associated with surgery, or for those who have a less active lifestyle[9].
- Surgical treatment: May be more suitable for active patients who wish to quickly return to physical or sports activities and who have an expectation of complete recovery with a lower risk of recurrence[6,10].

4. Complications or comorbidities

- Conservative treatment: May be safer for patients with significant comorbidities, such as diabetes or heart disease, which increase surgical risks[5].
- Surgical intervention: Indicated for healthy patients without contraindications to surgery, especially when the conservative approach fails or when there are complications, such as Achilles tendon injury[4,7].

5. Patient preferences

- Conservative treatment: For patients who prefer to avoid surgery or are concerned about recovery time and associated risks, conservative treatment is a logical choice[3,6].
- Surgical intervention: May be preferred by patients seeking a more definitive and quick solution to symptoms, especially if they have already tried and failed with conservative options[8].

6. Risk of recurrence

- Conservative treatment: Although effective for some, it has a higher rate of symptom recurrence (up to 30%) compared to surgery[9].
- Surgical treatment: Lower recurrence rate (about 10%) and therefore may be the best option for those who wish to reduce the risk of recurrent symptoms[4].

Complications arising from surgical treatment of Haglund's deformity can be minimized with careful planning, appropriate surgical techniques, and diligent postoperative follow-up. The following are some strategies that can help reduce the risk of complications:

1. Preoperative evaluation

- Comprehensive assessment: A detailed preoperative evaluation, including a complete medical history and physical examination, can identify potential risk factors for complications, such as diabetes, poor circulation, or previous surgeries in the affected area[1].

- Patient selection: Proper choice of candidates for surgery is crucial. Patients with severe symptoms who have not responded to conservative treatments and who do not have significant comorbidities are ideal candidates for surgery[4,5].

2. Surgical technique (includes positioning, access route, preservation of the calcaneal tendon, precise removal of the posterosuperior tuberosity, and neurovascular care).

- Minimally invasive surgery: Opting for minimally invasive techniques, such as endoscopic calcaneoplasty, can reduce the risk of infection, minimize tissue damage, and shorten recovery time[6].
- Proper tissue handling: Careful handling of soft tissues during surgery, avoiding excessive retraction or trauma to adjacent structures, helps reduce the risk of nerve injury and other complications[6].
- Adequate hemostasis: Ensuring adequate control of bleeding during surgery can minimize the risk of postoperative hematoma and reduce the likelihood of infection[5].

3. Postoperative care

- Surgical wound care: Proper wound care is essential to prevent infections. This includes keeping the surgical site clean, monitoring for signs of infection, and following up regularly with the healthcare provider[5,6].
- Physical therapy: Early and adequate physical therapy can help restore function, prevent stiffness, and reduce the risk of tendon adhesions or other complications related to immobility[6,7].
- Gradual return to activities: Encouraging a gradual return to load activities and avoiding excessive calcaneus stress during the initial recovery period can prevent complications such as tendon rupture or re-injury[7].

4. Monitoring and follow-up

- Regular follow-up: Regular postoperative visits allow early detection and management of complications, such as infection or delayed healing, enabling timely interventions, if necessary[5].
- Use of prophylactic measures: In some cases, antibiotics or prophylactic anticoagulants may be prescribed to reduce the risk of infections or thrombosis[5].

Conclusion

Haglund's disease represents a significant clinical challenge, especially in terms of proper management to ensure symptom improvement and quality of life for patients. The choice between conservative and surgical approaches should be based on a careful assessment of factors such as the severity of symptoms, response to initial treatment, patient preferences, and the risk of complications.

Conservative treatments, although less invasive, have a higher recurrence rate and may be insufficient for patients with significant bony deformities or severe symptoms. On the other hand, surgical interventions, particularly endoscopic calcaneoplasty, have shown superior outcomes in terms of pain relief and functionality, but must be accompanied by meticulous planning and rigorous postoperative care to minimize complications.

The therapeutic decision must be personalized to each patient's specific characteristics. Collaboration between the patient and medical team is crucial for choosing the most appropriate approach and ensuring that the benefits of treatment outweigh the risks. In addition, patient education on condition management and post-treatment expectations is critical to long-term success.

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Review

Multimodal analysis and reconstruction of medical images in the evaluation of foot and ankle pathologies: Clinical and technological perspectives

Diego Fernandes Lopes[1], **Daniel Santos da Silva**[2], **Rodrigo Schroll Astolfi**[3], **Victor Hugo Costa de Albuquerque**[4]

1. Instituto de Ortopedia e Traumatologia, Hospital das Clínicas da Universidade de São Paulo, São Paulo, SP, Brazil.
2. Departamento de Engenharia de Teleinformática, Universidade Federal do Ceará, Fortaleza, CE, Brazil.
3. Programa de pós-graduação de ciências médicas cirúrgicas, Universidade Federal do Ceará, Fortaleza, CE, Brazil.
4. Departamento de Engenharia de Teleinformática, Universidade Federal do Ceará, Fortaleza, CE, Brazil.

Abstract

Objective: To analyze recent literature on 3D reconstruction technologies and multimodal fusion of medical images in orthopedics, with a focus on foot and ankle applications, and to discuss their potential, limitations, and future directions.

Methods: This narrative review included original articles from 2010 to 2024 from PubMed, Scopus, and IEEE Xplore databases, using keywords related to "foot," "ankle," "3D reconstruction," "weight-bearing computed tomography," "machine learning," "augmented reality," and "multimodal fusion." Studies on 3D reconstruction, image evaluation algorithms, and integration of imaging modalities in orthopedics were selected, with particular emphasis on those related to the foot and ankle. Those not affiliated with the medical field or specialty were excluded. The extracted data covered authorship, year, imaging modality, population, objective, and main conclusions

Results: Twenty-one studies were included in four categories: (1) standing weight-bearing computed tomography (WBCT) of the ankle and knee (4 studies), with greater precision and reproducibility than 2D radiographs; (2) 2D-3D algorithms (6 studies) based on neural networks and statistical models, capable of generating 3D models from conventional exams; (3) machine learning (3 studies) for fracture classification and ligament diagnosis, with high accuracy in automatic detection; and (4) augmented/mixed reality (8 studies) applied to surgical navigation and training, improving accuracy, reducing surgical time and radiation, in addition to showing educational potential.

Conclusion: 3D reconstruction and multimodal fusion technologies provide new tools for evaluating foot and ankle pathologies. WBCT remains the gold standard for visualizing dynamic changes, but its restricted access can be mitigated using artificial intelligence for 3D reconstructions from conventional examinations. Advances in augmented reality and multimodal image fusion will permeate surgical diagnosis, planning, and execution, adding precision and safety in clinical practice.

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

Keywords: Foot; Ankle; 3D reconstruction; Weight-bearing; Computed tomography; Artificial intelligence; Augmented reality.

Introduction

The foot and ankle joints play an essential role in distributing body weight during gait. Due to its intricate anatomy and significant dynamic changes, multiple imaging modalities are often required for complete three-dimensional (3D) visualization of the structures involved, especially when observing structural changes in weight-bearing situations[1,2].

In this context, although computed tomography (CT) and magnetic resonance imaging (MRI) are widely employed, their limitations include the supine position during the exa-

Study performed at the Instituto de Ortopedia e Traumatologia da Universidade de São Paulo, São Paulo, SP, Brazil.

Correspondence: Diego Fernandes Lopes. Rua Dr. Ovídio Pires de Campos, 333, São Paulo, SP, Brazil. **Email:** flopesdiego@gmail.com. **Conflicts of interest:** None. **Source of funding:** None. **Date received:** July 2, 2025. **Date accepted:** January 23, 2026.

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mination, which makes functional assessment without weight-bearing unfeasible. Advances such as weight-bearing CT (WBCT) have demonstrated improved results, although cost and limited availability limit its widespread adoption[3-5].

Recent advances in artificial intelligence (AI), machine learning, and augmented reality (AR) have enabled 3D reconstructions from two-dimensional (2D) images and the integration of multiple imaging modalities. Convolutional neural networks have been applied for automatic segmentation and volumetric reconstruction of bones from conventional radiographs or tomographies. Multimodal fusion methods combine CT, MRI, and radiographic information to generate more detailed 3D models, while AR systems aid surgical navigation and the teaching of orthopedic procedures[6], thereby improving diagnostic and surgical accuracy.

This study aims to demonstrate the practical applications of AI in foot and ankle surgery and to highlight advances in related fields, thereby informing new research directions. Such projects may be the key to solving one of the great challenges of orthopedic surgeries, especially in foot and ankle surgery, which is that the clinical analysis of the pathologies is performed with the limb in orthostasis and with weight-bearing, but the corrective surgeries and complementary exams are performed with the patient in the decubitus position and without weight-bearing.

Therefore, the objective of this narrative review is to analyze recent literature on 3D reconstruction technologies and multimodal fusion of medical images in orthopedics, with a focus on foot and ankle applications, and to discuss their potential, limitations, and future directions.

Methods

This is a narrative review of the literature. The searches were conducted in the PubMed, Scopus, and IEEE Xplore databases between January and April 2025, using combinations of keywords in Portuguese and English: "pé," "tornozelo," "pé plano," "weight-bearing CT," "tomografia com carga," "reconstrução 3D," "realidade aumentada," "machine learning," and "multi-modal image fusion." The references of the included articles were also analyzed to identify additional studies.

Original studies on: (1) 3D reconstruction applied to foot, ankle, or lower limb exams; (2) AI algorithms or neural networks for segmentation, classification, or measurement of bone and joint structures; (3) multimodal fusion involving CT, MRI, radiography or WBCT; and (4) AR applications in surgical navigation or orthopedic training were included. Opinion articles, letters to the editor, and studies unrelated to orthopedics were excluded.

The screening consisted of reading titles and abstracts, followed by a full analysis of eligible texts. The extracted data included authors, year, study type, imaging modality, technology employed (WBCT, AI, AR, multimodal fusion), and main findings. Methodological evaluation metrics were not applied, given the descriptive nature of the review.

Results

Two hundred and thirteen records were retrieved, of which 32 articles were evaluated in full and 21 were included in the final synthesis. The studies were divided into four categories: (1) WBCT; (2) 2D-3D image reconstruction; (3) machine learning to evaluate fractures and ligament injuries; and (4) augmented/mixed reality. Table 1 presents its main characteristics.

After synthesizing the studies, it was observed that, despite the current superiority of WBCT in 3D evaluation, the limited availability and cost of the devices restrict their routine use. 2D-3D reconstruction algorithms have demonstrated that statistical models and convolutional networks can generate 3D reconstructions with millimeter-level accuracy, enabling the simulation of weight-bearing examinations from conventional radiographs. Machine learning studies on fracture and ligament injury detection have achieved accuracies greater than 90%[7,8], suggesting that AI can assist radiologists and surgeons in decision-making. Augmented reality applications have shown reductions in surgical time and radiation exposure, as well as greater accuracy in surgical navigation[9,10] and improved resident teaching[6].

The analysis of the included studies highlights the growing application of AI, 2D-3D reconstruction algorithms, multimodal fusion, and AR in orthopedics, with consistent performance in terms of accuracy, reproducibility, and clinical applicability.

Discussion

This review shows that the use of digital technologies in foot and ankle care has evolved consistently over the last decade, particularly in WBCT, 2D–3D reconstruction algorithms, machine learning, and AR. Despite the methodological heterogeneity of the included studies, there is a clear tendency to incorporate tools to assess image-based evaluation of real weight-bearing conditions and to improve diagnostic and therapeutic accuracy.

WBCT is established as the gold standard for 3D evaluation of orthostasis, enabling more accurate characterization of orthopedic deformities than conventional radiographs and other non-weight-bearing examinations[11,12]. However, the studies analyzed demonstrate that its high cost and restricted availability limit its routine use, particularly in resource-constrained health settings. In this scenario, 2D-3D reconstruction algorithms emerge as a promising alternative, enabling the generation of 3D models from widely available exams[13,14] and offering a pathway to expand access to 3D analysis in services without WBCT infrastructure.

The generation of 3D models from examinations involves critical steps: segmentation, in which the structures of interest are identified and separated from the others; registration, which aligns images in the same coordinate system, especially when different modalities are combined; and volumetric reconstruction, in which software transforms the data into a manipulable 3D model. Figure 1 presents a flowchart illustrating how the process would proceed.

These steps, intuitive to the human observer, pose technical challenges for AI algorithms, which need to be trained to distinguish anatomical boundaries within complex color scales. When such barriers are overcome, the resulting models can be applied to surgical planning, intraoperative navigation, and even 3D printing for educational and therapeutic purposes.

Machine learning, in turn, has shown potential to reduce interobserver variability and to accelerate the diagnosis of fractures and ligament injuries[15-17]. However, most of the

Table 1. Summary of articles evaluated

No.	Study	Study design	Objective	Imaging tests used	No. of exams/ cases evaluated
1	Astolfi et al. (2023)	Comparative retrospective diagnostic study	Compare expert accuracy vs. machine learning algorithm in detecting anterior talofibular ligament ankle injury	Magnetic resonance imaging (MRI)	321 images (ATFL lesion and normal)
2	Burssens et al. (2016)	Observational study	Validate a new method for measuring forefoot angles in WBCT scans, comparing with weight-bearing radiographs	WBCT and radiographs	60 exams
3	Butler et al. (2023)	Prospective case series (Augmented Reality in spine surgery)	To evaluate the efficiency and complications of AR in the percutaneous placement of vertebral pedicle screws	Intraoperative imaging + CT	164 cases, 606 screws
4	Cao et al. (2022)	Descriptive/anatomical study	Reconstruct three-dimensional fractures of the lateral malleolus and evaluate parameters to predict preoperative syndesmosis lesions	TC	148 cases
5	Godoy-Santos (2018)	Narrative review	Update on the use of WBCT on the foot and ankle	Not applicable	Not applicable
6	Kim et al. (2023)	Retrospective neural network validation study	Evaluate the utility of a neural network to perform a multivariate analysis of parameters present in ankle radiographs	Radiographs	1493 exams
7	Leão et al. (2024)	Prospective pilot study	Test parameters measured in WBTC to assess the instability of knees with chronic ACL injury	WBCT	05 cases
8	Lee et al. (2017)	Proof of concept/ method	Demonstrate a real-time multimodal image fusion AR method to guide orthopedic procedures	Fluoroscopy + CT	Not applicable
9	Li et al. (2021)	Computational method development	Compare a new multimodal image fusion method with established methods	MRI + PET-MRI + SPECT + CT	12 pairs of exams
10	Li et al. (2023)	Narrative review	Describe historical and technical aspects of the creation, development, and evolution of surgical navigation systems	Not applicable	Not applicable
11	Matthews (2021)	Narrative review	Review the literature on clinical application of AR in orthopedics	Not applicable	Not applicable
12	Montemagno et al. (2024)	Randomized clinical trial	To compare the performance of residents vs. attending physicians in the diagnosis of acetabular fractures with AR vs. 3D printing vs. CT	CT	Not applicable
13	Nguyen et al. (2023)	Technical methodological study	Develop for 3D reconstruction of lower limbs from orthogonal biplanar radiographs	Radiographs	13 pairs of radiographs
14	Olczak et al. (2021)	Retrospective study	Demonstrate the accuracy of a deep learning model in the radiographic classification of ankle fractures according to the AO/OTA 2018 classification	Radiographs	4941 exams
15	Ortolani et al. (2021)	Cross-sectional observational study	Demonstrate the advantages of measuring deviations and angles in the flatfoot through the use of 3D image reconstruction and WBCT	WBCT	21 patients
16	Pei et al. (2021)	Algorithm development study	Measure the hip-knee-ankle angle through a deep learning algorithm in lower limb radiography	Radiographs	398 exams
17	Polt et al. (2024)	In vitro comparative experimental study	Compare the technical accuracy of the conventional vs. AR-assisted method in calcaneal elongation with osteotomy using a bone model	Not applicable	120 models
18	Shiode et al. (2021)	Computational method development	Develop and test a neural network model to reconstruct 3D models of the distal portion of the forearm from radiographs	CT + Radiographs	173 CTs + 105 radiographs
19	Tu et al. (2021)	Pilot study/proof of concept	Evaluate AR navigation with HoloLens 2 to guide intramedullary distal stem block	Not applicable	Not applicable
20	Wang et al. (2016)	Technical-clinical pilot study	Demonstrate the benefits of the insertion accuracy of sacroiliac screws in cadaver models from the use of AR systems	CT + AR	06 cases
21	Zhao et al. (2020)	Technical experimental study	Evaluate CT cone beam performance with tilted rotary shaft in phantom/technical manipulation	CT	Not applicable

WBCT: Weight-bearing computed tomography; CT: Computed tomography; AR: Augmented reality; MRI: Magnetic resonance imaging; SPECT: Single photon emission computed tomography; PET: Positron emission tomography

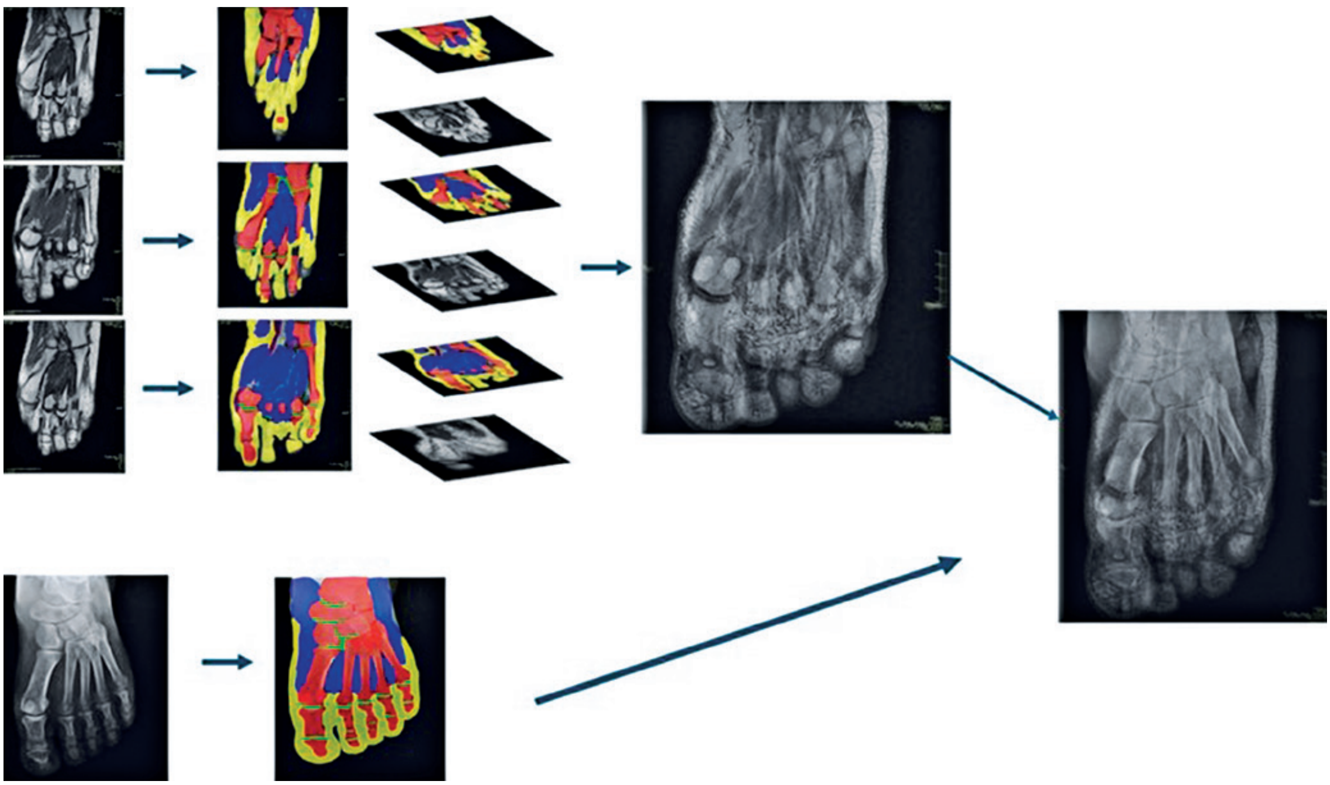

Figure 1. Flowchart of the steps for image fusion.

revised algorithms were trained on relatively small databases, lack external validation, and do not present impact assessments on clinical outcomes or cost-effectiveness. Thus, the routine incorporation of AI in orthopedic practice depends on prospective studies that overcome these limitations.

Fusion of images from different modalities (CT, MRI, radiographs) has been shown to be useful for optimizing soft-tissue visualization and guiding minimally invasive procedures, while AR systems have demonstrated greater accuracy in surgical navigation[18-21], reduced fluoroscopic exposure, and increased use in immersive training. However, most available studies address the spine, pelvis, or hip; in the foot and ankle, evidence remains incipient, limiting clinical extrapolations.

The practical implications of this review indicate that, although such technologies already demonstrate clear benefits, the field remains in a state of consolidation. For the foot and ankle orthopedist, this means access to tools with the potential to refine diagnosis, optimize surgical planning, and reduce complications, but which do not yet have robust clinical validation.

Among the research priorities identified are (1) clinical trials that evaluate the accuracy, applicability, and functional impact of technologies; (2) cost-effectiveness and accuracy studies that determine the feasibility and benefit of reconstruction algorithms to replace WBCT; and (3) multimodal fusion protocols based on broad datasets, increasing their validity and accuracy.

Therefore, although advances in 3D reconstruction, machine learning, and AR represent a milestone in the evolution of surgical diagnosis and planning, their incorporation into clinical practice still depends on the consolidation of evidence demonstrating not only technical performance but also direct patient benefit.

Conclusion

Three-dimensional reconstruction and multimodal image fusion represent significant advances in orthopedics, particularly for the evaluation of complex joints such as the foot and ankle. This review showed that such technologies increase diagnostic accuracy, favor surgical planning, and have potential for integration into navigation and training strategies. However, its large-scale clinical adoption remains limited by barriers including the scarcity of clinical studies, computational complexity, and the absence of standardized protocols.

From a clinical perspective, these tools may, in the future, aid the analysis of complex deformities and the performance of minimally invasive procedures with greater safety and reproducibility. For this potential to translate into real patient benefit, research efforts should focus on developing accessible and reproducible algorithms and creating robust databases for training and external validation. Studies focusing on clinical outcomes and cost-effectiveness will be fundamental to consolidating the application of these technologies in orthopedic practice.

Authors' contributions: Each author contributed individually and significantly to the development of this article: DFL *(https://orcid.org/0000-0002-3111-1630) Conceived and planned the activities that led to the study, bibliographic review, wrote the process, methodology, bibliographic review; DSS *(https://orcid.org/0000-0001-5670-1496) Participated in the review analysis; RSA *(https://orcid.org/0000-0001-6022-7336) Conceived and planned the activities that led to the study, participated in the review process, data article; VHCA *(https://orcid.org/0000-0003-3886-4309) Methodology, data analysis. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Original Article

Addressing the challenge of first metatarsal head ulcers: preliminary results of a minimally invasive base osteotomy approach

Valeria Lopez[1], **Emanuel Gonzalez**[1], **Laura Gaitan**[1], **Gaston Slullitel**[1], **Maria Jose Varela**[1], **Gonzalo Alvarez**[1], **Juan Pablo Randolino**[1]

1. Instituto de Ortopedia y Trauma Dr. Jaime Slullitel, Hospital Italiano de Rosario, Rosario 2000, Santa Fe, Argentina.

Abstract

Objective: This study reports preliminary results of a minimally invasive first metatarsal base osteotomy for chronic plantar diabetic foot ulcers (DFUs).

Methods: Five consecutive patients with neuropathic DFUs under the first metatarsal head, unresponsive to at least six weeks of conservative treatment, were enrolled. Patients with severe ischemia, osteomyelitis, or significant soft tissue loss were excluded. All underwent a dorsomedial percutaneous incomplete wedge osteotomy of the first metatarsal base, performed by a single surgeon. Ulcer care and postoperative follow-up were conducted according to standardized protocols.

Results: All ulcers healed within weeks, with no cases of radiographic nonunion, transfer lesions, or recurrence at a mean follow-up of 12 months. One superficial infection resolved with oral antibiotics.

Conclusion: These preliminary findings suggest that minimally invasive first metatarsal base osteotomy may be a feasible surgical option for selected patients with chronic plantar DFUs refractory to conservative care. Larger, controlled studies are warranted to validate its safety, effectiveness, and long-term outcomes.

Level of evidence IV, Case series.

Keywords: Metatarsal bones; Diabetic foot; Osteotomy; Treatment outcome.

Introduction

Diabetic foot ulcers (DFUs) represent one of the most devastating complications of diabetes mellitus (DM), affecting between 19% and 34% of patients during their lifetime[1]. Chronic plantar diabetic foot ulcers are associated with high recurrence, infection, and amputation rates[2].

Peripheral neuropathy, vascular disease, and altered plantar biomechanics—especially overload at the metatarsal heads – are the main contributors to ulcer development[3].

Ulcers located beneath the first metatarsal head present therapeutic challenges due to unique biomechanical, anatomical, and pathophysiological factors. This region endures some of the highest plantar pressures during the gait cycle, particularly during toe-off, which hinders healing even under standard off-loading protocols. Moreover, the hallux bears a disproportionate load when limited joint mobility – common in diabetic patients – increases forefoot pressure and predisposes the adjacent metatarsal heads to ulceration[4].

Conservative management, including total contact casting, custom orthoses, and shoe modifications, remains the first-line treatment[2]. However, recurrence rates are as high as 40% within the first year and 65% within five years[3].

When conservative measures fail, surgical intervention is required to reduce plantar pressure and promote ulcer healing.

In recent years, minimally invasive surgery (MIS) has gained popularity as a therapeutic option for forefoot disorders, particularly hallux valgus. Concurrently, in diabetic patients

Study performed at the Instituto de Ortopedia y Trauma Dr. Jaime Slullitel, Hospital Italiano de Rosario, Rosario 2000, Santa Fe, Argentina.

Correspondence: Valeria Lopez. San Luis 2534 Rosario, 2000 Stana Fe, Argentina. **Email:** vlastegiano@gmail.com. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** October 29, 2025. **Date accepted:** February 25, 2026.

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with recurrent neuropathic plantar ulcers, the biological advantages of MIS have led to the publication of several studies reporting its use in the central metatarsals and, to a lesser extent, in the first metatarsal[5]. Regarding the first metatarsal, available evidence is limited, and most authors describe distal first-ray elevation procedures[5,6]. To date, we are not aware of any publications specifically addressing proximal MIS osteotomies of the first metatarsal for the treatment of recurrent neuropathic plantar ulcers.

The aim of this study is to assess ulcer healing and 12-month recurrence in patients with diabetic foot ulcers beneath the first metatarsal head who underwent minimally invasive first metatarsal base osteotomy.

Methods

Ethical approval was obtained before patient enrollment, and all patients received and signed an informed consent form. Five patients with first metatarsal ulcers who consecutively sought consultation at our outpatient clinic were enrolled. Patients with DM with peripheral neuropathy, who failed at attempted six weeks of conservative treatment were included. Failure of conservative treatment was defined as the absence of reduction in the ulcer's longest axis (in millimeters), further deepening of the lesion, or a decrease in the long axis of less than 50%. Current guidelines and expert reviews generally recommend an initial period of conservative offloading of at least six weeks, with many authors extending this period to 2–3 months before considering surgical intervention, depending on ulcer evolution and anatomical risk factors. In the present case, however, we judged that in this specific anatomical area the risk of progression to osteomyelitis – along with the difficulty of treating it once established – outweighed the potential risks associated with surgery. Exclusion criteria consisted of severe ischemia, as evaluated by an ankle-brachial index < 0.5, who were not candidates for previous revascularization, patients with active osteomyelitis, or those with severe soft tissue loss at the site of osteotomy.

All patients underwent a systematic evaluation that included laboratory tests for white blood cell count, erythrocyte sedimentation rate (ESR), and C-reactive protein (CRP), as well as metabolic control assessed by HbA1c or fructosamine. Nutritional status was evaluated through serum albumin, vitamin D3, and platelet count. Plain anteroposterior (AP) and lateral (L) weight-bearing radiographs were taken at the initial consultation, at four weeks postoperative, and at the final follow-up visit. Magnetic resonance imaging (MRI) was performed in patients with ulcers persisting for more than four weeks to identify findings compatible with bone involvement.

Patients were classified according to the University of Texas Diabetic Wound Classification System (UTDWC), considering ulcer size, depth, and the presence or absence of infection and ischemia[7]. Ulcer dimensions were assessed using the method described by Coughlin et al.[8] with a transparent sheet at each clinical visit to record the ulcer diameter. The principal axes of the lesions were then measured manually based on the traced ulcer area.

Although additional biomechanical and functional assessments – such as plantar pressure analysis, functional outcome scores, objective measurement of first metatarsal elevation, and first metatarsophalangeal joint mobility – may provide complementary information, their routine use in patients with active plantar ulcers and diabetic neuropathy is limited by issues of feasibility and reliability; therefore, in keeping with previously published minimally invasive metatarsal osteotomy series, this study focused on ulcer healing, absence of recurrence, and radiographic union as the primary outcome measures.

Owing to the limited sample size, no inferential statistical analysis was undertaken, and outcomes are reported using descriptive statistics only.

Surgical technique

All procedures were performed by the same surgeon experienced in percutaneous and minimally invasive techniques, and informed consent was obtained prior to surgery. With the patient in the supine position under regional anesthesia, the base of the first metatarsal was identified using fluoroscopic guidance. A dorsomedial portal was established (Figure 1A), and with a 4.0 mm drill, an incomplete dorsal-based wedge osteotomy was performed, thinning the plantar cortex (Figure 1B, C, and D). By applying a dorsiflexion maneuver from the plantar aspect, the osteotomy was closed, thereby elevating the first metatarsal (Figures 2 and 3). In the patient with a pre-ulcerative lesion, a compression 4.0 mm partially threaded screw from medial dorsal to plantar lateral was placed. Patients were instructed to bear weight from the day of the procedure using a postoperative shoe, which was discontinued once the wound had fully epithelialized. Additionally, local debridement of the ulcer to viable tissue was performed during the same surgical procedure.

Postoperative ulcer care was conducted according to each patient's pre-established protocol.

Results

A total of five patients (4 men and 1 woman) were enrolled in this initial experience (Table 1). All DFUs were located under the first metatarsal head (Figure 1). All patients attempted conservative treatment for at least six weeks that consisted of wound healing with calcium alginate in the wound bed and off-loading with an anterior offload postoperative shoe.

No patients depicted radiographs or MRIs consistent with osteomyelitis at the first metatarsal head or at the osteotomy level.

Patients progressed to bone healing in a mean of 8.2 weeks (6 to 10 weeks), and ulcer healing was achieved in a mean of 51 days (15 to 90 days) (Figure 4).

Internal fixation was selectively used in only one patient with a pre-ulcerative lesion and intact soft tissues to enhance

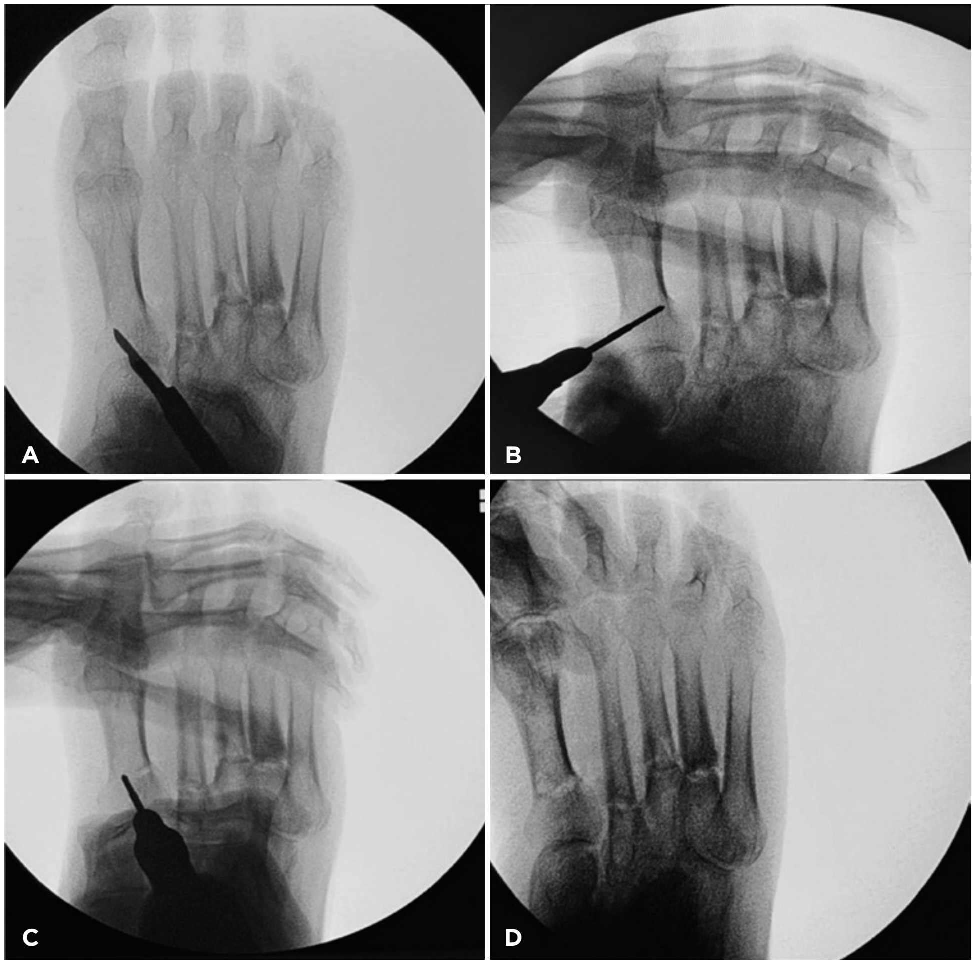

Figure 1. A. Marking of the percutaneous portal height at the base of the first metatarsal. B and C. Percutaneous osteotomy performed using a Shannon burr. D. Completed osteotomy.

perceived osteotomy stability; in contrast, fixation was deliberately avoided in patients with open plantar ulcers to minimize infection risk, a strategy that introduces technical heterogeneity and is acknowledged as a limitation of this small case series.

One superficial infection at the osteotomy site occurred, successfully treated with oral antibiotics. We did not observe radiological nonunion in any of the cases. No transfer lesions or recurrence were recorded during a mean follow-up of 12 months.

Discussion

Although the successful treatment of DFUs often requires a combination of approaches – such as wound care, infection control, revascularization, and pressure offloading – pressure redistribution is generally considered the most critical element in the treatment of neuropathic DFUs. Currently, the gold standard for offloading is the use of a non-removable, knee-high device with a properly fitted foot–device interface, which has been shown to optimize ulcer healing. When this strategy fails, emerging evidence suggests that both surgical and alternative nonsurgical offloading methods may accelerate the healing process in plantar ulcers that remain refractory to standard conservative care[9].

The first metatarsal region presents a particular challenge because of the difficulty in effectively off-loading this area and the rapid progression of ulcers that develop there. Further complicating the issue, motor neuropathy-induced deformities such as hallux rigidus or claw hallux biomechanics shift load laterally, concentrating pressure on the first metatarsal head and hindering off-loading efforts[10].

Minimally invasive osteotomies of the lesser metatarsals have proven to be an efficient off-loading technique, with a low complication rate due to minimal soft tissue damage[11]. However, to the best of the authors' knowledge, there is

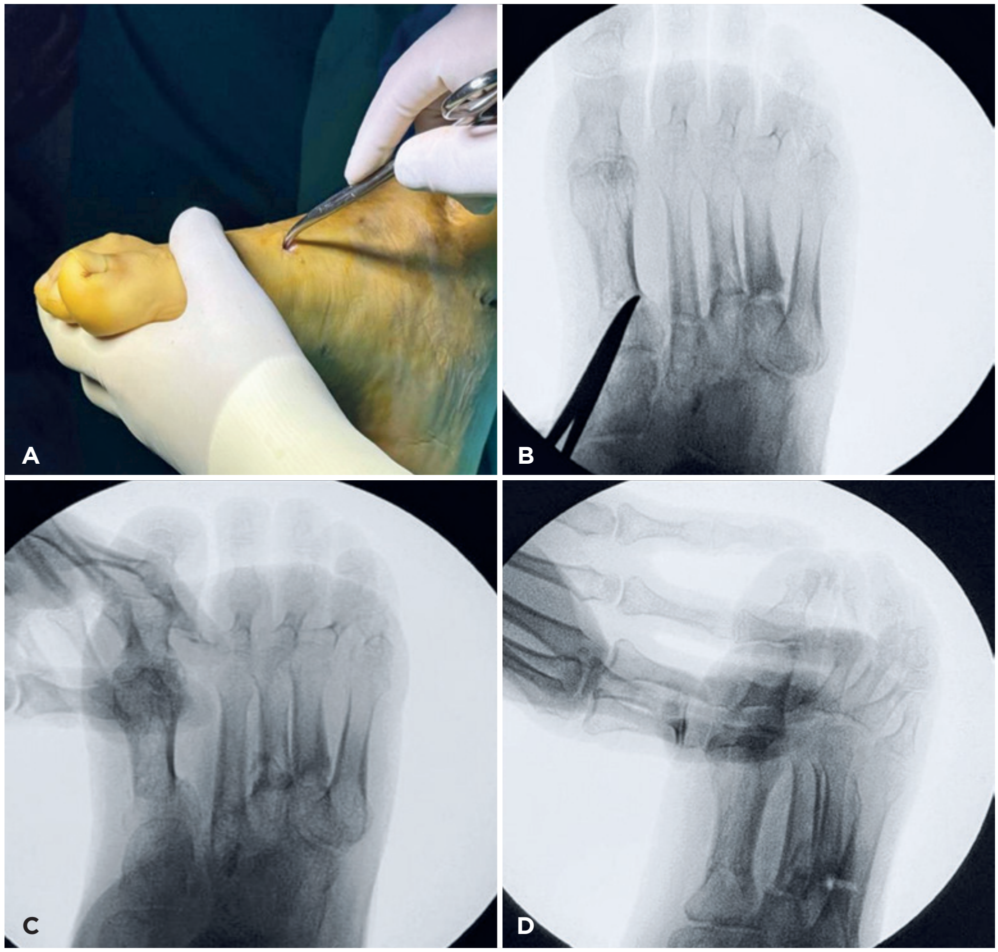

Figure 2. A and B. Elevation maneuver of the first metatarsal using a Halsted clamp. C and D. Intraoperative fluoroscopic control.

Figure 3. A. Sagittal fluoroscopic view showing guidewire placement for internal fixation. B. Final fixation with a 4.0 mm cannulated screw.

Table 1. Demographic data of the five patients.

Patient	Age	Sex	UTDWC	Time to closure	Time to bone healing	Complications	FU
1	54	F	A1	15 d	8 w	No	12.1 m
2	71	M	A3	60 d	10 w	SSI	12.5 m
3	70	M	A2	59 d	8 w	No	16 m
4	70	M	A3	92 d	9 w	No	21 m
5	73	M	A3	28 d	6 w	No	18 m

F: Feminine; M: Masculine; UTDWC: University of Texas Wound Classification; A1: Superficial lesion without penetration; A2: Wound that penetrates tendon or capsule; A3: Wound that penetrates bone or joint; SSI: Surgical site infection.

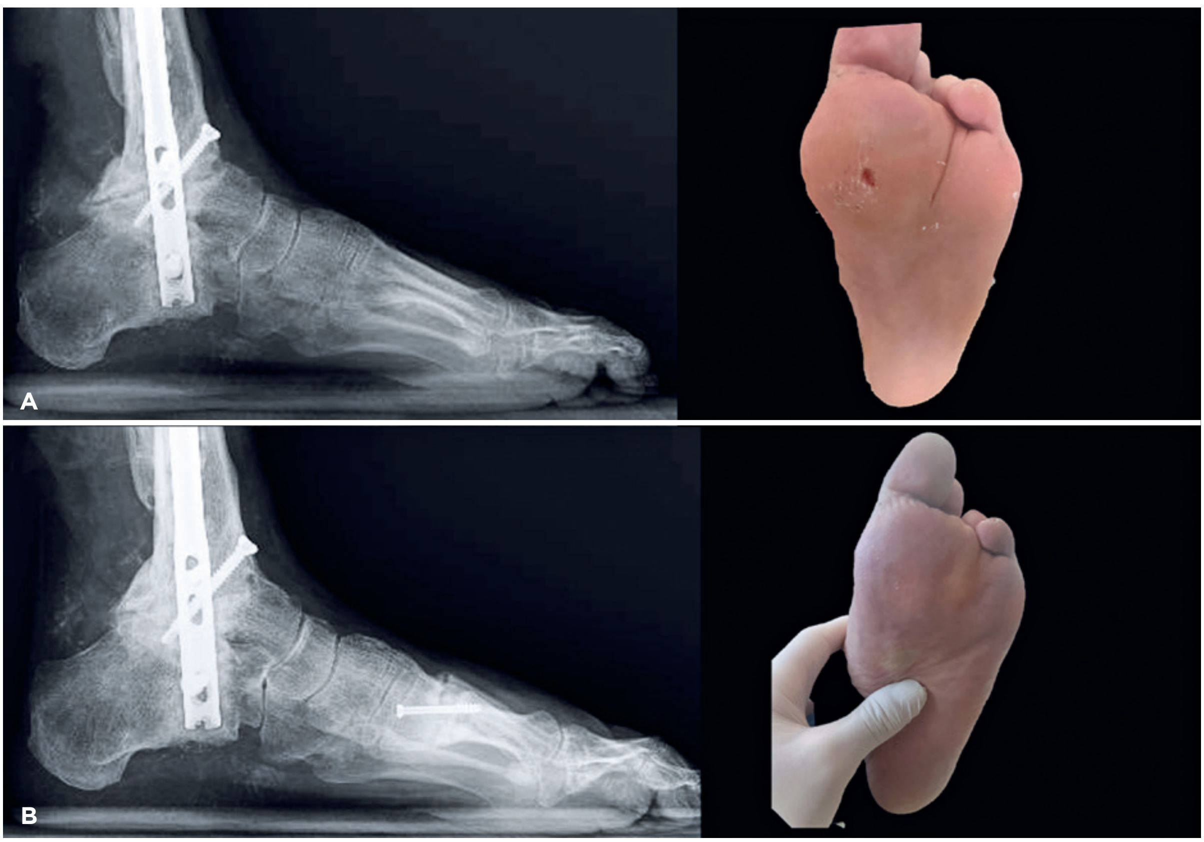

Figure 4. A. Plantar ulcer at the head of the first metatarsal and preoperative radiograph. B. Clinical and radiographic follow-up at three months postoperatively.

currently no available evidence on the application of this procedure to the first metatarsal.

Our findings support the role of minimally invasive metatarsal osteotomy as an effective and safe technique for the treatment of chronic plantar diabetic ulcers, particularly in patients unresponsive to conservative measures. All ulcers healed in a relatively short period, with minimal complications and no recurrence during follow-up.

Evidence on lesser metatarsal osteotomies may be extrapolated to this scenario. Our results are consistent with those of Tamir et al. (2016)[11], who reported that minimally invasive floating metatarsal osteotomy resolved resistant or recurrent ulcers in 85% of cases, with low complication rates. Similarly, Biz et al. (2017)[2] demonstrated in a prospective series that distal metatarsal diaphyseal osteotomies (DMDO) promoted ulcer healing and significantly improved functional outcomes, with no recurrence at mid-term follow-up. Uncertainties about recurrence over the long term were further addressed in 2024, in a study confirming the long-term safety and efficacy of DMDO, reporting improved functional scores and the absence of recurrence[12].

On a technical note, although the clinical implications of first and lesser metatarsal minimally invasive osteotomies may be similar, a first metatarsal base osteotomy is more demanding, as it is essential to avoid complete perforation of the plantar cortex to maintain a 'locked closed' osteotomy in dorsiflexion. Moreover, this technique is intrinsically less stable. The addition of a 4.0-mm screw may enhance stability, but in the context of an open lesion, its use must be carefully considered.

Limitations of this study include the small sample size and the lack of a control group. Furthermore, the absence of long-term follow-up precludes conclusions regarding late recurrence or transfer lesions. Prospective randomized trials are needed to validate these findings and to compare MIS osteotomies with other surgical strategies.

Conclusion

As demonstrated by studies on the lesser metatarsals, which provide more robust evidence, minimally invasive metatarsal osteotomy has been shown to be a safe, effective, and reproducible technique for managing chronic plantar diabetic foot ulcers that are unresponsive to conservative treatment. Our limited series does not allow us to draw conclusions regarding the validation, efficacy, or effectiveness of this approach. Consequently, these findings should not be considered definitive, but rather as preliminary, hypothesis-generating observations that support the feasibility of this technique and warrant further investigation in larger studies with longer follow-up.

Authors' contributions: Each author contributed individually and significantly to the development of this article: VL *(https://orcid.org/0000-0001-6345-5991) Performed the surgeries, data collection, and approved the final version; EG *(https://orcid.org/0000-0002-6109-1431) Participated in the review process performed the bibliographic review; LG *(https://orcid.org/0000-0002-1621-3081) Participated in the review process performed the bibliographic review; GS *(https://orcid.org/0000-0002-4842-7447) Interpreted the results of the study, participated in the review process and approved the final version; MJV *(https://orcid.org/0009-0006-3942-9674) Assisted the data collection and survey of the medical records; GA *(https://orcid.org/0000-0001-5826-690X) Assisted the data collection and survey of the medical records; JPR * (https://orcid.org/0000-0003-3709-8163) Assisted the data collection and survey of the medical records; 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

Implant failure after ankle arthrodesis versus total ankle arthroplasty: a matched- cohort study

Cláudia Diniz Freitas[1], Natália Helena Tau[1], Deivid Ramos dos Santos[2], Eduardo Cezar Silva dos Santos[1,2]

1. Hospital Alemão Oswaldo Cruz, São Paulo, SP, Brazil.
2. Porto Dias Hospital, Belém, PA, Brazil.

Abstract

Objective: To compare the risk of implant failure between ankle arthrodesis and total ankle arthroplasty using propensity score matching and time-to-event analysis.

Methods: This multicenter retrospective cohort study used data from the TriNetX Global Collaborative Network. Adult patients aged 18-100 years with ankle osteoarthritis who underwent ankle arthrodesis or total ankle arthroplasty between 2012 and 2023 were included. Propensity score matching (1:1) was performed to balance demographic and clinical covariates. Implant failure was the primary outcome. Survival analyses were conducted using Kaplan-Meier methods and Cox proportional hazards regression, with follow-up censored at implant failure, death, loss to follow-up, or three years after the index date.

Results: Among 7,973 eligible patients, 2,745 matched pairs were analyzed. Implant failure was more frequent after ankle arthrodesis than after total ankle arthroplasty (17.4% vs 12.0%; $p < 0.001$). Arthrodesis was associated with a higher hazard of implant failure (HR 1.94; 95% CI, 1.75-2.15). Elevated hemoglobin A1c independently increased the risk of failure, whereas body mass index and serum albumin did not.

Conclusion: Ankle arthrodesis was associated with a significantly higher risk of implant failure compared with total ankle arthroplasty. Metabolic optimization, particularly glycemic control, should be considered in surgical decision-making.

Level evidence III; Retrospective Comparative Study.

Keywords: Ankle; Arthrodesis; Arthroplasty, replacement, ankle; Risk factors.

Introduction

End-stage ankle arthritis is a debilitating condition associated with chronic pain, functional limitation, and reduced quality of life[1]. When conservative management fails, surgical intervention is often required, with ankle arthrodesis and total ankle arthroplasty representing the two primary surgical treatment options[2]. While ankle arthrodesis has long been considered the gold standard due to its predictable pain relief and durability, total ankle arthroplasty has gained increasing acceptance as a motion-preserving alternative that may offer functional advantages in selected patients[3]. However, the optimal surgical strategy remains controversial, particularly with respect to implant durability and the long-term risk of failure[4].

Implant failure following ankle surgery is a clinically meaningful outcome, frequently necessitating revision procedures that are technically complex and associated with substantial morbidity and healthcare costs[5]. Prior comparative studies evaluating implant failure between ankle arthrodesis and total ankle arthroplasty have reported inconsistent results[6]. These discrepancies are likely attributable to heterogeneity in patient selection, surgical indications, and follow-up duration, as well as inadequate adjustment for baseline differences between treatment groups[4-6]. Importantly, patients undergoing ankle arthrodesis often present with a higher burden of comorbidities, which may confound observed associations between procedure type and postoperative outcomes[5-6].

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

Correspondence: Eduardo Cezar Silva dos Santos. 1815, Treze de Maio Street, Postal code: 01323-903, São Paulo, Brazil. **Email:** eduardocezar.ortopedia@gmail.com. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** December 19, 2025. **Date accepted:** March 4, 2026.

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Metabolic and nutritional factors are increasingly recognized as critical determinants of surgical outcomes in orthopedic procedures[7]. Poor glycemic control, commonly assessed by hemoglobin A1c (HbA1c), has been consistently associated with impaired wound healing, increased risk of infection, and implant-related complications[8]. Similarly, hypoalbuminemia reflects compromised nutritional and inflammatory status and has been linked to adverse postoperative outcomes, while elevated body mass index (BMI) may contribute to mechanical overload and altered biomechanics around the ankle joint[9]. Despite their biological plausibility and clinical relevance, these factors are infrequently incorporated into comparative analyses of ankle arthrodesis and arthroplasty, particularly within time-to-event frameworks.

Propensity score matching (PSM) offers a robust method for minimizing baseline confounding in observational studies by balancing measured covariates between treatment groups. When combined with survival analysis using Cox proportional hazards modeling, this approach allows for an adjusted comparison of the risk of implant failure over time while accounting for both treatment selection bias and independent risk factors[10]. To date, large-scale studies integrating PSM with multivariable time-to-event analysis to evaluate implant failure following ankle arthrodesis versus total ankle arthroplasty remain limited.

Therefore, the purpose of this study is to compare the risk of implant failure between ankle arthrodesis and total ankle arthroplasty in a large multicenter retrospective cohort, using propensity score matching to balance demographic and clinical covariates, followed by an adjusted Cox proportional hazards model accounting for metabolic and nutritional factors, including hemoglobin A1c, serum albumin, and body mass index.

Methods

Study design and data source

This was a multicenter, retrospective, observational cohort study conducted using data from the TriNetX Global Collaborative Network, a federated health research network providing access to de-identified electronic medical records (EMRs) from large healthcare organizations (HCOs) worldwide. The network used for this analysis comprised 161 HCOs, all of which responded to the query. TriNetX provides access to diagnoses, procedures, medications, and laboratory data recorded during routine clinical care. The analysis was generated using the TriNetX platform on December 14, 2025. Because all data were de-identified, institutional review board approval and informed consent were not required. This ensures that users of the platform do not have access to any protected health information or personal data. The data is centralized in the Innovation, Research, and Education DataLab of the Oswaldo Cruz German Hospital in São Paulo, which serves as a hub institution for TriNetX in Brazil. Data access is available through the TriNetX research network at https://live.trinetx.com.

As with all analyses based on administrative and electronic health record data, the TriNetX platform does not provide detailed information on implant brand, fixation method, surgical approach, deformity severity, or surgeon volume and experience.

Study population

Adult patients aged 18 to 100 years with a diagnosis of ankle osteoarthritis were eligible for inclusion. Osteoarthritis was defined using ICD-10-CM codes for primary osteoarthritis of the ankle and foot (M19.07), post-traumatic osteoarthritis of the ankle and foot (M19.17), or secondary osteoarthritis of the ankle and foot (M19.27).

Patients were included if they underwent either ankle arthrodesis or total ankle arthroplasty between January 1, 2012, and December 31, 2023. The date of the qualifying surgical procedure was defined as the index date.

Cohort definitions

Two mutually exclusive cohorts were defined based on procedural codes:

Cohort 1: Ankle arthrodesis – Patients with qualifying osteoarthritis diagnoses who underwent ankle arthrodesis, identified using CPT and SNOMED procedure codes for ankle arthrodesis. Patients with any record of ankle arthroplasty were excluded from this cohort.

Cohort 2: Total ankle arthroplasty – Patients with qualifying osteoarthritis diagnoses who underwent ankle arthroplasty, identified using CPT codes for total ankle replacement. Patients with any record of ankle arthrodesis were excluded from this cohort.

Patients with neoplastic diagnoses (ICD-10-CM C00–D49) were excluded from both cohorts.

Outcome definition

The primary outcome was implant failure, defined using ICD-10 codes T84.0, T84.1, and T84.2 (complications of internal orthopedic prosthetic devices, implants, or grafts). Importantly, this code represents a composite, coding-based outcome and does not distinguish among specific failure mechanisms. In ankle arthrodesis, implant failure codes may reflect nonunion-related hardware failure, symptomatic or broken fixation devices, or infection. In contrast, in total ankle arthroplasty, the same codes more commonly capture prosthesis-related complications such as loosening, wear, or infection. Therefore, 'implant failure' should be interpreted as a heterogeneous administrative outcome rather than a uniform biological or mechanical failure across procedures.

Covariates

Baseline characteristics assessed at or prior to the index date included demographic variables (age, sex, race, and ethnicity), comorbidities (including diabetes mellitus, chronic kidney disease, hypertension, obesity, nicotine dependence, chronic obstructive pulmonary disease, Charcot arthropathy, venous insufficiency, and prior infection), prior procedures, medication exposure (including systemic corticosteroids and anabolic steroids), and laboratory parameters.

Variables of interest included anthropometric measurements and laboratory parameters. Anthropometric assessment included BMI. Laboratory variables were analyzed using a complete-case approach. Hemoglobin A1c and serum albumin were available for a subset of patients only (approximately 14% and 23% of the matched cohort, respectively), and no data imputation was performed, as this is not supported by the TriNetX platform.

Propensity score matching

To minimize confounding due to baseline differences between cohorts, PSM was performed using all listed baseline characteristics. Propensity scores were estimated using logistic regression, with cohort assignment (ankle arthrodesis versus total ankle arthroplasty) as the dependent variable.

Propensity score matching was performed using nearest-neighbor matching in a 1:1 ratio, without an explicit caliper width, consistent with the standard implementation of TriNetX platform. Covariate balance before and after matching was assessed using standardized mean differences, with values below 0.10 considered indicative of adequate balance.

Although PSM achieved adequate balance for most baseline covariates, small residual imbalances remained for selected metabolic and nutritional variables, including hemoglobin A1c, BMI, and serum albumin. Given their known clinical relevance and standardized mean differences exceeding 0.10 after matching, these variables were prespecified for inclusion in subsequent multivariable time-to-event analyses.

Statistical analysis

Baseline characteristics were summarized using means and standard deviations for continuous variables and percentages for categorical variables. Comparisons between cohorts were performed using appropriate statistical tests as implemented within the TriNetX platform.

Outcome analyses were conducted on the propensity score-matched cohorts. The risk of implant failure was evaluated using risk differences, risk ratios, and odds ratios along with their corresponding 95% confidence intervals (95% CI).

Time-to-event analyses were performed using Kaplan-Meier survival curves, with differences between cohorts assessed using the log-rank test.

To account for residual imbalance after propensity score matching, a multivariable Cox proportional hazards regression model was constructed, including variables with standardized mean differences greater than 0.10 following matching, specifically hemoglobin A1c, BMI, and serum albumin levels, in addition to the exposure variable (ankle arthrodesis versus total ankle arthroplasty).

Patients were followed for up to three years from the index surgical procedure. This 3-year follow-up window was selected a priori to ensure uniform outcome ascertainment across the study period and to minimize bias related to differential loss to follow-up in a large, multi-institutional administrative database. This time frame captures most early and intermediate implant-related complications while maintaining consistent censoring across cohorts. Follow-up was censored at the time of implant failure, death, loss to follow-up, or at 3 years after the index date, whichever occurred first. Death was treated as a censoring event and was not explicitly modeled as a competing risk. Although patients were included between January 2012 and December 2023, all time-to-event analyses were anchored to the individual index date, allowing uniform assessment of outcomes within the predefined 3-year follow-up window and appropriate handling of right censoring.

The proportional hazards assumption for the Cox regression model was assessed using graphical inspection of log-log survival plots and evaluation of Schoenfeld residuals. No clinically meaningful violations of the proportional hazards assumption were identified.

Additional multivariable analysis

Given the residual imbalance after propensity score matching, an additional Cox proportional hazards regression model was constructed. This model included covariates with standardized mean differences greater than 0.10 after matching, specifically BMI, hemoglobin A1c, and serum albumin levels. The primary exposure variable was cohort membership (ankle arthrodesis versus total ankle arthroplasty).

Hazard ratios (HRs) with 95% CI were reported. Statistical significance was defined as a two-sided p-value < 0.05.

The statistical programs used were R and SPSS Statistics version 19.0, in addition to four programs or language tools intrinsic to the TriNetX platform.

Ethics

The data used in this study were acquired from TriNetX (https://trinetx.com), a global federated health research network that provides real-time anonymized EMRs provided by HCOs around the world. All TriNetX data are de-identified and anonymized in compliance with HIPAA (The US Health Insurance Portability and Accountability Act); thus, informed consent was not necessary, and the study was granted an exemption from specific institutional ethics board approval.

Results

A total of 412,471 patients with a diagnosis of ankle osteoarthritis between 2012 and 2023 were identified. After applying exclusion criteria, 7,973 patients who underwent surgical treatment were included in the final analysis (Figure 1). Of these, 4,825 underwent ankle arthrodesis and 3,148 underwent total ankle arthroplasty.

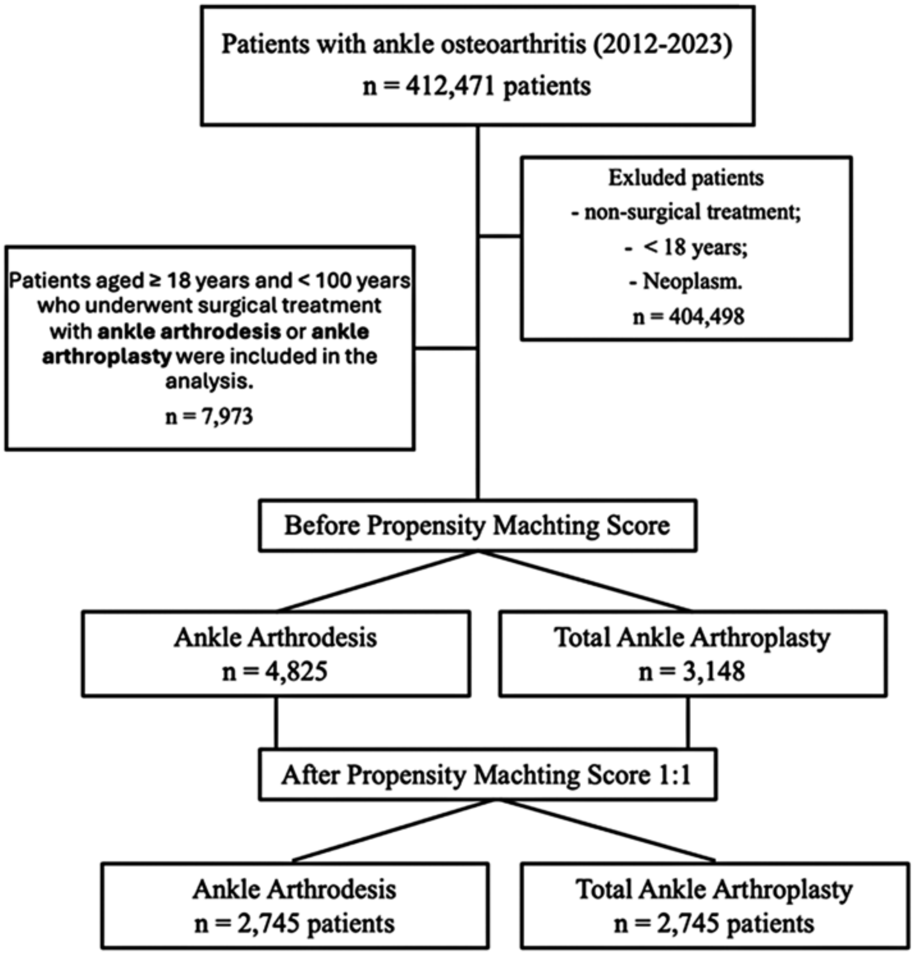

Figure 1. Flow diagram of cohort identification, eligibility, and propensity score matching.

Before propensity score matching, patients in the ankle arthrodesis cohort were younger than those undergoing arthroplasty (mean age, 55.3 ± 14.1 vs 60.9 ± 12.0 years) and had a higher prevalence of several comorbidities, including smoking, diabetes mellitus, obesity, chronic kidney disease, and Charcot arthropathy. Significant baseline differences were also observed in race, ethnicity, prior ankle-related procedures, and laboratory values. Several covariates demonstrated standardized mean differences (SMDs) > 0.10, indicating substantial imbalance between groups.

Preoperative laboratory data were incompletely available. Hemoglobin A1c values were present for 13.7% and 14.7% of patients in the arthrodesis and arthroplasty groups, respectively, while serum albumin levels were available for 23.4% and 23.8%.

Propensity score matching generated 2,745 well-balanced pairs (n = 5,490 total). After matching, age was comparable between cohorts (59.7 ± 12.6 vs 59.7 ± 12.0 years), and most demographic and clinical variables were adequately balanced (SMDs < 0.10) (Table 1, Figure 2). Small residual imbalances persisted for hemoglobin A1c, serum albumin, and BMI; these variables were subsequently adjusted for in multivariable Cox regression analyses.

All comparative outcome analyses were performed using the matched cohorts.

Outcome

Outcomes analyses were performed in the propensity score-matched cohorts. After exclusion of patients who experienced implant failure prior to the defined time window, 2,074 patients remained in the ankle arthrodesis cohort and 2,249 in the total ankle arthroplasty cohort. A total of 361 implant failures occurred in the ankle arthrodesis group and 271 in the total ankle arthroplasty group.

Table 1. Baseline demographic and clinical characteristics before and after propensity score matching in patients undergoing ankle arthrodesis and total ankle arthroplasty

CID-10	Demographics	Before Propensity Score Matching							After Propensity Score Matching						
		Ankle Arthrodesis (n=4,825)			Total Ankle Arthroplasty (n=3,145)			Std diff.	Ankle Arthrodesis (n=2,745)			Total Ankle Arthroplasty (n=2,745)			Std diff.
		Mean ± SD	n	% cohort	Mean ± SD	n	% cohort		Mean ± SD	n	% cohort	Mean ± SD	n	% cohort	
	Age at Index	55.3 ± 14.1	4,825	100%%	60.9 ± 12.0	3,148	100%	0.430	59.7 ± 12.6	2,745	100%	59.7 ± 12.0	2,745	100%	0.001
	Male		2,757	57,1%		1,701	54%%	0.063		1,515	55.2%		1,515	54.7%	0.010
	Female		2,066	42,8%%		1,446	45,90%	0.063		1,229	44.8%		1,244	45.3%	0.011
	Race														
	Whrite		3,840	79,6%		2,702	85.8%	0.166		2,349	85.6%		2,340	85.2%	0.009
	Black or African American		460	9.5%		171	5.4%	0.156		167	6.1%		168	6.1%	0.002
	Unknown Race		298	6.2%		106	3.4%	0.132		102	3.7%		104	3.8%	0.004
	Ethnicity														
	Not Hispanic or Latino		3,727	77.2%		2,502	79.5%	0.054		2,188	79.7%		2,169	79.0%	0.017
	Hispanic or Latino		300	6.2%		90	2.9%	0.162		81	3.0%		88	3.2%	0.015
	Unknown Ethnicity		798	16.5%		556	17.7%	0.030		476	17.3%		488	17.8%	0.011
	Comorbidity														
F17.2	Smoking		600	12.4%		170	5.4%	0.249		167	6.1%		169	6.1%	0.003
F10	Alcohol abuse		92	1.9%		23	0.7%	0.103		22	0.8%		22	0.8%	<0.001
I10	Essential (primary) hypertension		1,560	32.3%		939	29.8%	0.054		795	29.0%		799	29.1%	0.003
E08-E13	Diabetes mellitus		896	18.6%		252	8,00%	0.315		242	8.8%		251	9.1%	0.011
M14.67	Charcôt's joint, ankle and foot		314	6.5%		10	0.3%	0.346		10	0.4%		10	0.4%	<0.001
J44	chronic obstructive pulmonary disease		190	3.9%		59	1.9%	0.123		55	2,0%		56	2.0%	0.003
I87.2	Venous insufficiency (chronic) (peripheral)		65	1.3%		25	0.8%	0.054		23	0.8%		24	0.9%	0.004
Z22.322	Carrier or suspected carrier of Methicillin resistant Staphylococcus aureus		34	0.7%		10	0.3%	0.054		10	0.4%		10	0.4%	<0.001
N18	Chronic kidney disease (CKD)		286	5.9%		80	2.5%	0.169		63	2.3%		73	2.7%	0.023
E66	Overweight and obesity		900	18.7%		415	13.2%	0.150		364	13.3%		372	13.6%	0.009
	Body Mass Index (Kg/m2)	33.2 ± 7.8	3,597	74.5%	31.3 ± 6.0	2,256	71.7%	0.274	32.6 ± 7.4	1,964	71.5%	31.5 ± 6.1	1,994	72.6%	0.161
	> 30 kg/m^2		2,359	48.9%		1,306	41.5%	0.149		1,197	43.6%		1,194	43.5%	0.002
	Procedure														
	Surgical Procedures on the Leg (Tibia and Fibula) and Ankle Joint		873	18.1%		218	6.9%	0.343		210	7.7%		213	7.8%	0.004
	Aspiration and/or intra-articular injection of the ankle		455	9.4%		501	15.9%	0.196		336	12.2%		359	13.1%	0.025
	Medications														
	Anabolic steroids		10	0.2%		10	0.3%	0.022		10	0.4%		10	0.4%	<0.001
	Corticosteroid for systemic use		1,630	33.8%		1,034	32.8%	0.020		816	29.7%		846	30.8%	0.024
	Fracture														
S82.309D	History of closed distal tibial fracture with complete healing.		74	1.5%		10	0.3%	0.127		10	0.4%		10	0.4%	<0.001
S82.309E	History of an open Gustilo-Anderson type I or II distal tibial fracture, healed		74	1.5%		10	0.3%	0.127		10	0.4%		10	0.4%	<0.001
	Laboratory														
	Hb1Ac (mg/dL)	6.5 ± 1.5	1,024	21.2%	5.9 ± 0.9	448	14.2%	0.468	6.2 ± 1.2	375	13.7%	5.9 ± 1.0	403	14.7%	0.228
	Serum albumin level (mg/dL)	3.9 ± 0.6	1,434	29.7%	4.2 ± 0.4	767	24.4%	0.480	4.1 ± 0.5	642	23.4%	4.2 ± 0.4	654	23.8%	0.229
	< 6.0 mg/dL		1,434	29.7%		767	24.4%	0.121		642	23.4%		654	23.8%	0.010
	Total serum protein level (mg/dL)	7.1 ± 0.7	1,374	28.5%	7.1 ± 0.5	727	23.1%	0.006	7.1 ± 0.6	621	22.6%	7.1 ± 0.5	616	22.4%	0.068
	<3.5 mg/dL		10	0.2%		0	0,0%	0.064		10	0.4%		0	0	0.086

The cumulative risk of implant failure was higher among patients undergoing ankle arthrodesis than among those undergoing total ankle arthroplasty (17.4% vs 12.0%). This corresponded to an absolute risk difference of 0.054 (95% CI, [0.032-0.075]; p < 0.001). Ankle arthrodesis was associated with a significantly increased relative risk of implant failure (risk ratio, 1.45; 95% CI, 1.25-1.67) and higher odds of failure (OR, 1.54; 95% CI, 1.29-1.82) compared with total ankle arthroplasty (Table 2).

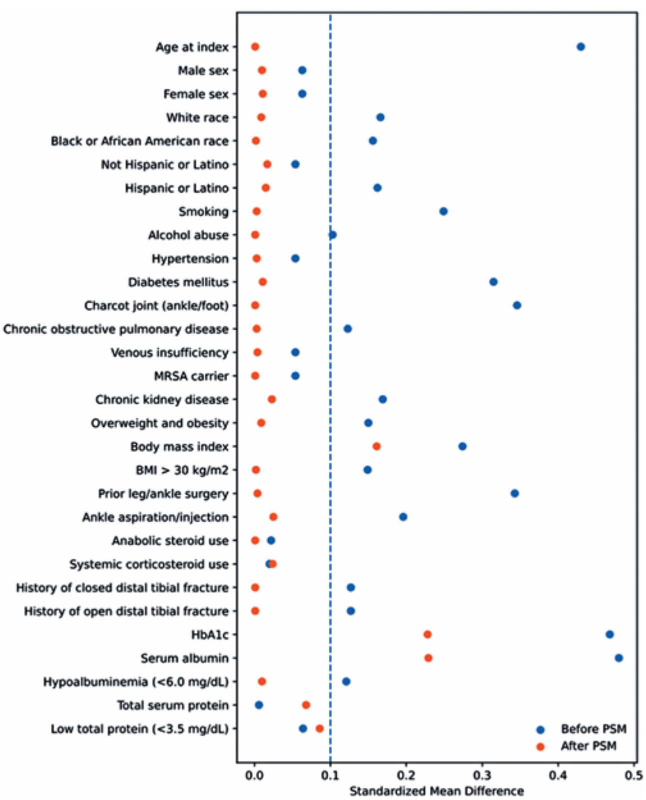

Figure 2. Standardized mean differences demonstrating covariate balance before and after propensity score matching.

Survival analysis

Kaplan-Meier survival analysis demonstrated significantly lower implant survival in the ankle arthrodesis cohort over the follow-up period. Survival probability at the end of the observation window was 77.9% for ankle arthrodesis and 84.5% for total ankle arthroplasty. The difference between groups was statistically significant by log-rank testing (χ^2 = 29.48; p < 0.001). Median survival was not reached in either cohort during the study period (Figure 3).

Cox proportional hazards analysis

This model was specifically designed to adjust for residual metabolic and nutritional imbalances observed after propensity score matching.

In multivariable Cox proportional hazards analysis, adjusting for residual metabolic and nutritional imbalances, ankle arthrodesis remained independently associated with an increased hazard of implant failure compared with total ankle arthroplasty (HR, 1.94; 95% CI, 1.75-2.15; p < 0.001). Elevated hemoglobin A1c was also independently associated with an increased risk of implant failure (HR, 1.36; 95% CI, 1.21-1.54; p < 0.001). Serum albumin level (HR, 1.10; 95% CI, 0.99-1.22; p = 0.074) and BMI (HR, 1.08; 95% CI, 0.97-1.22; p = 0.150) were not independently associated with implant failure after adjustment (Table 3).

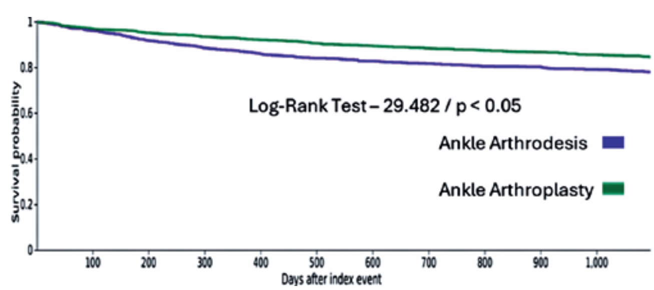

Figure 3. Kaplan-Meier survival curve for implant failure comparing ankle arthrodesis and total ankle arthroplasty.

Table 2. Association for implant failure after propensity score matching

Cohort		Cohort statistic		
		Patients in cohort	Patients with outcome	Risk
1	Ankle Arthrodesis	2,074	361	17,4%
2	Total Ankle Arthroplasty	2,249	271	12%

Risk difference	Risk difference			Risk ratio		Odds ratio	
	95% CI	z	p	Risk ratio	95% CI	Odds ratio	95% CI
5.4%	(0.032-0.075)	4.98	0.0	1.445	(1.249-1.671)	1.538	(1.297-1.824)

* 671 patients in the ankle arthrodesis cohort and 496 patients in the total ankle arthroplasty cohort were excluded from the results because they had the outcome prior to the time window. CI: Confidence interval.

Table 3. Multivariable Cox proportional hazards regression analysis evaluating factors associated with implant failure after ankle arthrodesis and total ankle arthroplasty

Covariate	Hazard ratio	Coefficient	Standard error	z	P > |z|	95% CI
Arthrodesis or Arthroplasty	1.944	0.665	0.053	12.586	0.000	(1.753-2.156)
Hemoglobin A1c/	1.369	0.314	0.060	5.253	0.000	(1.218-1.540)
Albumin (mg/dL)	1.103	0.098	0.055	1.787	0.074	(0.991-1.229)
BMI (kg/m^2)	1.089	0.085	0.059	1.439	0.150	(0.970-1.223)

BMI: Body mass index; CI: Confidence interval.

Discussion

In this retrospective comparative cohort study using the international TriNetX database, ankle arthrodesis was associated with a significantly higher risk of coded implant failure than total ankle arthroplasty. This association remained consistent across multiple analytic approaches, including propensity score matching and adjusted time-to-event analyses.

A key consideration when interpreting these findings is the conceptual non-equivalence of the outcome between procedures. Although both involve implanted materials, administrative implant failure codes capture different underlying mechanisms. In arthrodesis, these codes often reflect nonunion-related hardware complications or symptomatic fixation, whereas in arthroplasty, they more commonly represent prosthesis-specific failures, such as loosening, wear, or infection. Consequently, the outcome reflects heterogeneous implant-related complications rather than directly comparable biological or mechanical failures and may systematically disadvantage the arthrodesis cohort.

Historically, ankle arthrodesis has been regarded as a durable and reliable treatment for end-stage ankle osteoarthritis, particularly among younger patients and those with greater comorbidity burdens[11]. Early comparative studies suggested similar intermediate-term survivorship between arthrodesis and arthroplasty, but were limited by small sample sizes, heterogeneous implant designs, and non-standardized selection criteria[12-14]. Haddad et al.[15] emphasized these methodological challenges in their systematic review. With modern implant designs and improved surgical techniques, more recent prospective and multicenter investigations have demonstrated progressively better outcomes following total ankle arthroplasty[16,17]. Saltzman et al.[18] reported acceptable early survivorship of the STAR prosthesis, and Daniels et al.[19], in the COFAS multicenter study, observed comparable survival with superior functional outcomes for arthroplasty. Similar advantages were described by Glazebrook et al.[20].

The present study extends this literature by leveraging a large, contemporary population and applying propensity score matching to reduce indication bias. These real-world data suggest a higher rate of coded implant-related complications following arthrodesis compared with arthroplasty.

Our findings are consistent with national registry and meta-analytic data demonstrating improved durability of modern ankle arthroplasty. Henricson et al.[21] reported favorable long-term survival in registry analyses, while Zaidi et al.[22] showed progressive improvements in arthroplasty outcomes over time. Functional and gait studies further suggest that biomechanics are more physiological and that quality of life is better after arthroplasty compared with fusion[23,24].

Several limitations warrant consideration. This analysis relies on administrative ICD-10 and CPT coding, which limits clinical detail and introduces potential misclassification. Important operative variables—including implant type, fixation method, surgical technique, deformity severity, bone quality, and surgeon experience—were unavailable and may contribute to residual confounding. In addition, the ICD-based implant failure definition aggregates heterogeneous complications that are not directly comparable between procedures and may overestimate failure after arthrodesis. Laboratory data were incomplete, restricting some analyses to complete cases and potentially introducing selection bias. Although longer-term outcomes at five or ten years are clinically relevant, extended follow-up in administrative databases is often affected by incomplete longitudinal capture and differential attrition. A 3-year horizon was therefore selected to balance clinical relevance with methodological robustness. Finally, death was treated as a censoring event rather than explicitly modeled as a competing risk, which may bias estimates if mortality differs between groups.

Despite these limitations, this study is strengthened by its large sample size, multicenter international data source, contemporary timeframe, and adjustment for key metabolic and nutritional factors. The consistency of results across analytic strategies supports the robustness of the observed association.

Conclusion

In this large propensity score-matched analysis of patients with ankle osteoarthritis, ankle arthrodesis was associated with a significantly higher risk of coded implant failure compared with total ankle arthroplasty. These findings suggest that, when patient-specific factors permit, total ankle arthroplasty may represent a durable alternative to arthrodesis in appropriately selected patients. Future prospective studies incorporating detailed radiographic parameters, implant-specific data, and patient-reported outcomes are needed to further refine surgical decision-making and optimize patient selection.

Author' contributions: Each author contributed individually and significantly to the development of this article: ECSS *(https://orcid.org/0000-0001-5018-3923) Conceived and planned the activities that led to the study, wrote the article, participated in the review process, approved the final version; interpreted study results, participated in the review process; and participated in the review process; CDF *(https://orcid.org/0000-0002-6649-2066), NHT *(https://orcid.org/0009-0002-8116-819X), and DRS* (https://orcid.org/0000-0002-7558-0359) Interpreted study results, participated in the review process. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Original Article

A long harvest of the flexor hallucis longus provides grafts that are more suitable for large Achilles defects

Diego A. Belling Segovia[1], Milán F. Zárate Leal[2], Renato Andrade[3], Tania Diaz Sanchez[4], Xavier Martin Oliva[5]

1. Hospital Nacional Daniel Alcides Carrión, Lima, Perú.
2. Fundación Valle del Lili, Cali, Colombia.
3. Medical Centre of Excellence, Porto, Portugal.
4. Faculty of Medicine and Health Sciences, University of Barcelona, Spain.
5. Faculty of Medicine, University of Barcelona, Barcelona, Spain.

Abstract

Objective: To compare the short (zone 1) and intermediate (zone 2) harvest zones of the flexor hallucis longus (FHL) tendon to a long harvest site at the interphalangeal joint of the hallux (zone 3).

Methods: Fourteen fresh-frozen cadaveric lower limbs were used to measure the FHL tendon length across zones 1, 2, and 3, tendon thickness, calcaneal tunnel length, percentage of tendon inside the tunnel, and the relation between the base of the first metatarsal and the medial plantar nerve.

Results: In the short harvest, the mean FHL tendon length was 22.9 ± 4.5 mm with the ankle in neutral position, and 33.2 ± 4.1 mm with the ankle in 15º of plantarflexion. Mean FHL thickness was 6.2 ± 0.8 mm. The mean calcaneal tunnel length was 44.1 ± 4.2 mm, and the mean length of the tendon traversing the bone tunnel was 21 ± 3.2 mm, while covering a mean of 48.5% of tunnel length. The FHL length at the intermediate harvest was 48.9 ± 5.7 mm with a mean distance of 24 ± 4.8 mm between the base of the first metatarsal and the medial plantar nerve. The FHL length was the longest during the long harvest, at 128.6 ± 7.1 mm.

Conclusion: The short harvest provided FHL grafts that covered only 48.5% of the calcaneal tunnel. The long harvest provides longer FHL grafts suitable for large Achilles defects, in which augmentation with the remaining FHL tendon may be needed.

Level of evidence V.

Keywords: Tendons; Achilles tendon; Hallux; Ankle; Cadaver.

Introduction

While the Achilles tendon represents the most robust tendinous structure in the human anatomy, it remains a frequent site of complete rupture[1,2] and the incidence has been increasing in the last few decades[3-5]. Although the increasing trend is to treat Achilles tendon tears non-surgically[4], surgical treatment may be indicated[6], especially in chronic cases[7]. Surgical strategies for Achilles reconstruction vary, ranging from direct apposition to complex augmentation involving synthetic scaffolds or autologous transfers, depending on the chronicity and gap size of the lesion[1,7].

The strip of the tensor fasciae latae or tendon allograft is commonly used for Achilles tendon reconstruction[7]. However, these tissues are avascular, more prone to infection, lack an intact and functional muscle belly, and do not provide the natural stability of an autograft[8]. Functional muscle-tendon free flaps involve microsurgical skills and may result in prolonged rehabilitation[8]. Instead, tendon transfers are ideal to augment or fully substitute an incompetent Achilles tendon when the defect is between 3 and 6 cm[7]. Tendon transfer to reconstruct the Achilles tendon is usually accomplished using the peroneus brevis tendon or the flexor hallucis longus (FHL) tendon, with comparable long-term functional results[7,9].

Study performed at the Department of Anatomy and Human Embryology, Faculty of Medicine, University of Barcelona, Spain.

Correspondence: Diego A. Belling Segovia. Alameda de la arquitectura 107, block 12, dpto 502, San Borja 15036, Lima, Peru. **Email:** diegobellingsegovia@gmail.com. **Conflicts of interest:** None. **Source of funding:** None. **Date received:** January 10, 2026. **Date accepted:** March 09, 2026.

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Anatomically situated as the most posterior constituent of the deep posterior compartment, the FHL lies near the typical zone of Achilles tendon rupture. In terms of biomechanical output, it serves as the primary accessory plantar flexor, surpassed in torque only by the triceps surae, yet exceeding the contractile force of both the peroneus brevis and the flexor digitorum longus. The FHL muscle acts synergistically with the triceps surae, with a mechanical axis that resembles the Achilles tendon[10]. Following transposition, the FHL demonstrates significant physiological plasticity, with documented compensatory hypertrophy reaching up to 52%[11], and the FHL muscle belly provides a vital vascularized pedicle, thereby introducing an auxiliary blood supply to the notoriously hypovascular 'watershed area' of the Achilles tendon[1]. Despite the predictable diminution of hallux flexion power following FHL transposition, subjective and objective functional outcomes remain high, as most patients successfully adapt to this compensatory change[12-14].

Conventional FHL harvesting occurs either at the level of the subtalar joint (zone 1), immediately distal to the posterior sulcus, or at the intersection of the flexor digitorum longus, known as the knot of Henry (zone 2). However, during the reconstruction of large Achilles defects, these harvest locations may result in an inadequate tendon length[8]. The long FHL harvesting can be done at the level of the base of the hallux (zone 3) to obtain a substantially longer tendon graft[8]. The long FHL harvesting technique has been previously described[8], but it remains important to understand if this harvesting technique is consistent and reliable for harvesting longer FHL grafts.

The objective of this cadaveric study is to compare the FHL tendon length as harvested in zones 1, 2, and 3, while also measuring other important tendon-specific metrics of the long FHL harvest. It was hypothesized that harvesting the FHL tendon at zone 1 would not always provide an adequate graft length for large Achilles, resulting in insufficient graft-to-tunnel length.

Methods

The study was performed in the Department of Anatomy and Human Embryology at the University of Barcelona. In accordance with the Spanish legal and ethical regulations regarding anatomical donation, 14 fresh-frozen cadaveric specimens (Table 1) were obtained through an institutional body donation program for analysis. In the absence of a preliminary sample size calculation, the study used the total cohort of available ankle specimens to maximize the statistical power within the constraints of the donor program. All cadaveric specimens were free of any signs of previous surgery or trauma, congenital or developmental deformities, or inflammatory ankle arthritis. No anatomic variants of the FHL tendon were observed.

Three incisions were planned for the long FHL harvest: the primary posterior-medial, the midfoot, and the hallux digital sulcus incision (Figure 1). For practical purposes, the skin and subcutaneous tissue were removed from the plantar and medial region of the foot.

Table 1. Demographic properties of study specimens

	Specimen (n = 14)
Age at donation	
Mean ± SD	84.5 ± 13.5
Median (Min-Max)	87.5 (55-95)
Side	
Right	7 (50%)
Left	7 (50%)
Sex	
Male	3 (21.4%)
Female	11 (78.6%)

SD: Standard deviation.

Figure 1. Three incisions are planned for the long flexor hallucis longus harvest: the primary posteromedial surgical incision (a), the midfoot (b), and the hallux digital sulcus (c).

The harvesting procedure started with the dissection and identification of the medial plantar nerve over the fascia of the flexor hallucis brevis (FHB). For intermediate harvest, the base of the first metatarsal was used as a useful anatomical reference, for which it was measured the distance between the middle area of the base of the first metatarsal and the medial plantar nerve, since the plantar nerve is at the highest risk of iatrogenic injury in this plantar approach (Figure 2). Following these initial preparations, the dissection and measurement of the tendon length at zones 1, 2, and 3 proceeded.

For zone 1, the dissection followed a posterior-medial approach in the ankle. The aponeurotic sheath overlying the posterior compartment was incised in a cranio-caudal

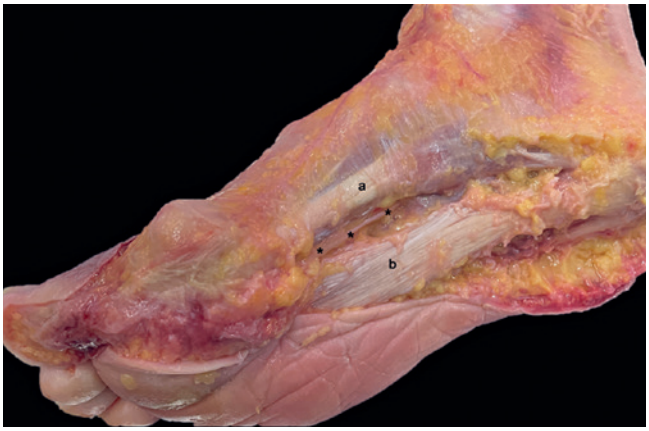

Figure 2. In the medial plantar incision, we identify the abductor hallucis (a), the plantar fascia (b), and the medial plantar nerve over the flexor hallucis brevis fascia (*).

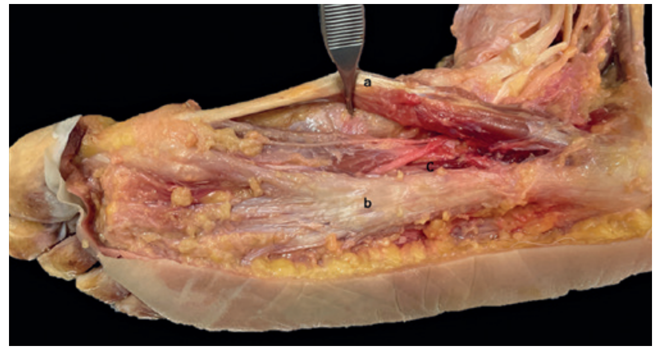

Figure 3. In the medial plantar incision, the abductor hallucis muscle (a) and the plantar fascia (b) are retracted away from one another, and by flexing the great toe, the flexor hallucis longus tendon (c) is identified just deep to the abductor hallucis muscle between the two heads of the flexor hallucis brevis over its aponeurosis.

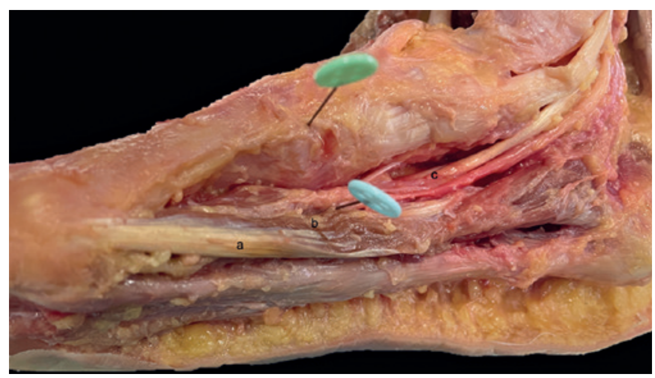

Figure 4. The abductor hallucis muscle (a) was then reflected plantarwardly with the flexor hallucis brevis (b) to expose the flexor digitorum longus and flexor hallucis longus decussation in the midfoot at the master knot of Henry (c).

direction to enable visualization of the superficial and deep muscle groups, followed by blunt dissection to isolate the FHL muscle belly with its tendon. The neurovascular bundle of the posterior tibia was identified within its characteristic adipose investment; its proximity to the FHL medial border required diligent protection during surgical exposure. Following the FHL mobilization from the posterior talar sulcus, the tendon length was quantified. These measurements were obtained under two specific conditions: with the ankle at 0° (neutral) and at a 15° plantarflexion. The FHL was then completely released, and the thickness was measured.

For zone 2, the abductor hallucis muscle (AHM) and plantar fascia were retracted away from each other, and by flexing the great toe. The FHL tendon was identified just deep to the AHM, between the two heads of the FHB over its aponeurosis (Figure 3). The AHM was then reflected plantarwardly with the FHB to expose the flexor digitorum longus (FDL) and FHL in the midfoot, at the master knot of Henry (Figure 4).

FHL harvesting in zone 3 is easier because it is superficial at the level of the distal hallux phalanx insertion. The FHL tendon was harvested via a posteromedial incision; maximal graft length was achieved by performing the transection at the posterior sustentaculum with the ankle and first digit in 15° of plantarflexion. To mitigate the risk of iatrogenic injury to the adjacent neurovascular bundle, the transection was executed in a medial-to-lateral direction using sharp dissection. Controlled tension was applied during retrieval to ensure the integrity of the musculotendinous interface.

The FHL autograft transfer was simulated in all cadaveric specimens to measure the graft-to-bone-tunnel length and ratio. The procedure followed the FHL (zone 1) harvesting, and a Krackow whipstitch using 2-0 Ethibond suture was applied. A 7-mm drill hole was then created directly in the midline and anterior to the Achilles tendon insertion on the superior aspect of the calcaneal tuberosity. This drill hole was created with a slightly lateral trajectory from the entry point, similar to the technique previously described by Hong et al.[15] and Ferrero-Recaséns et al.[16]. Following measurement of the bone tunnel dimensions, the FHL tendon stump was shuttled into the calcaneus via a guidewire. The fixation sutures were exteriorized through a lateral plantar incision. To determine the extent of tendon-to-bone contact, the FHL length residing within the tunnel was recorded at 15° of plantarflexion, measured from the tunnel entry point to the distal end of the graft (Figure 5). The tendon graft length with ankle plantar flexion was compared to the tunnel length to calculate the graft-to-tunnel ratio (%).

All measurements were made with a digital caliper and recorded in millimeters (mm). Measurements were tabulated for each specimen and summarized using descriptive analysis to calculate means and standard deviations from all 14 specimens.

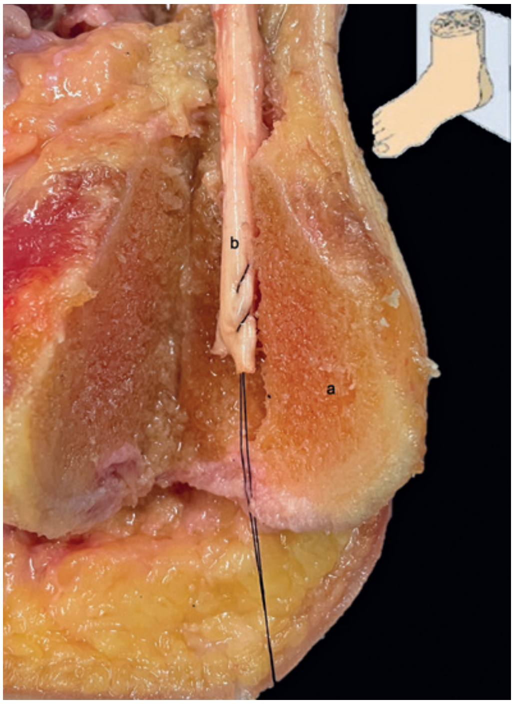

Figure 5. Coronal view of the calcaneus (a) with the flexor hallucis longus tendon (b) transected inside. The short harvest (zone 1) results in approximately half of the tendon being inside the calcaneal tunnel.

Results

In the short harvest, the mean FHL tendon length was shorter with the ankle in neutral position (22.9 ± 4.5 mm, range 15 to 30) than with the ankle in 15º of plantarflexion (33.2 ± 4.1 mm, range 26 to 38). The FHL thickness was 6.2 ± 0.8 mm (range 5 to 8). The calcaneal osseous tunnel exhibited a mean longitudinal dimension of 44.1 mm ± 4.2 mm (range 38 to 52), and the mean intraosseous FHL tendon length situated within the calcaneal tunnel was 21.0 mm ± 3.2 mm (range 15 to 26), while covering 48.5% of the tunnel length (Table 2).

In the intermediate harvest, the mean FHL tendon length was 48.9 ± 5.7 mm (range 39 to 56), and in the long harvest, the mean length was the longest with 128.6 ± 7.1 mm (range 120 to 141).

The mean distance between the base of the first metatarsal and the medial plantar nerve was 24 ± 4.8 mm (range 19 to 33).

Discussion

This cadaveric study provides anatomical data about the short, intermediate, and long harvest of the FHL tendon. It is difficult to acquire an adequate FHL tendon length for the reconstruction of large Achilles tendon defects. Hansen[17] was among the first to describe the method for harvesting the FHL tendon using a single posteromedial incision (zone 1). While the short-harvest technique is often reported to provide over 70% of the FHL tendon graft in the osseous

Table 2. Tunnel and flexor hallucis longus size metrics for short, intermediate, and long harvest

Specimen No.	Calcaneal tunnel length (mm)	Short harvest (Zone 1)					Intermediate harvest (Zone 2)	Long harvest (Zone 3)	Distance between the base of the 1st metatarsal to the medial plantar nerve (mm)
		Tendon length (mm)		Tendon length (mm) (plantar flexion) inside the tunnel	Tendon graft (plantar flexion) to tunnel length ratio (%)	Thickness (mm)	Tendon length (mm)		
		In neutral position	In plantar flexion						
1	38	26	37	15	39	6	56	128	31
2	42	18	26	18	43	6	51	129	33
3	41	15	28	23	56	6	48	128	19
4	47	30	34	19	45	8	56	140	21
5	45	23	38	21	47	7	53	120	22
6	39	15	28	18	46	6	46	120	22
7	39	26	38	24	62	6	39	126	24
8	42	21	31	18	43	7	54	125	19
9	45	24	33	23	51	6	39	120	30
10	45	23	33	22	49	6	49	124	29
11	45	23	38	21	47	6	53	130	20
12	51	23	30	20	39	7	48	130	24
13	46	28	36	26	62	5	51	141	20
14	52	26	35	26	50	5	42	139	22
Mean	44.1	22.9	33.2	21	48.5	6.2	48.9	128.6	24
SD	4.2	4.5	4.1	3.2	7.3	0.8	5.7	7.1	4.8

SD: Standard deviation.

tunnel at all times[15], the present cadaveric study found that the mean coverage ratio was 48.5%, with none of the specimens surpassing the 70% cut-off. One possible reason for this finding may be related to the fact that in the present study, the short FHL graft (22.9 ± 4.5 mm) was not measured while performing maximum plantar flexion or by excessive traction of the FHL at the time of fixation in the tunnel, due to the risk of possible tear of the muscle belly. Another potential reason may be that Hong et al.[15] compared the total FHL length (short harvest) against the tunnel length, whereas in the present study, only the FHL length inside the tunnel was considered. When measured as in the present study, it provides a more accurate estimate of the actual FHL length within the bone tunnel.

To optimize the longitudinal dimensions of the FHL graft, the tendon can be divided at its midfoot intersection with the flexor digitorum longus (the knot of Henry) using a double-incision technique[10]. However, even an intermediate harvest technique (48.9 ± 5.7 mm) can result in a suboptimal tendon length for large Achilles defects and is insufficient for concomitant augmentation transfer of the remaining FHL tendon. Distal retrieval of the FHL tendon at the hallux base[8] yields a significantly longer graft (128.6 ± 7.1 mm), providing sufficient longitudinal dimension for virtually all Achilles tendon reconstruction requirements. Due to the frequent presence of intertendinous connections between the FHL and the FDL[18], it is recommended to make three incisions (Figure 1) when making a long harvest (zone 3) to release the FHL in the midfoot.

Moreover, performing a double incision instead of the single incision technique when harvesting the FHL tendon may provide a longer FHL graft[19].

The mean FHL thickness and the calcaneal tunnel length were provided to guide the orthopedic surgeon while implementing the short FHL harvesting technique.

When performing the calcaneal tunnel length, a mean length of 44.1 ± 4.2 mm is expected, and therefore, adjust the FHL graft to fit at least 15 mm inside the tunnel. For example, in anterior cruciate ligament reconstruction, histological maturation and the subsequent biomechanical integrity of the tendon-bone interface are significantly compromised at the six-week postoperative mark if the intraosseous graft length is less than 15 mm[20]. Maximizing FHL tendon graft length within the bone tunnel and minimizing tendon-tunnel diameter mismatch will maximize the strength of a tendon-bone tunnel complex[21]. The mean thickness of the FHL will help the surgeon determine the minimum tunnel diameter and when to choose the most suitable tenodesis screw, with thicker FHL grafts allowing larger screws (rather than suturing the folded FHL to itself). Fixation utilizing bioabsorbable interference screws demonstrated superior biomechanical resistance to pull-out forces when compared to the conventional 'loop-and-suture' technique, in which the FHL graft is secured to itself using #1 Ticron suture after transosseous passage[22].

The FHL harvest carries inherent risks, including iatrogenic damage to the medial plantar nerve when harvesting in zone 2. A previous cadaveric study[23] performed FHL harvesting in zone 2 and measured the distance from the medial plantar nerve to the FHL's proximal fibrous zone (2A) and distal fascial zone (2B). The proximity of the medial plantar nerve to the FHL's tendon sheath creates a considerable risk of iatrogenic nerve injury when surgical procedures are performed in zone 2B. The distance between the base of the first metatarsal and the medial plantar nerve can serve as an important landmark in the plantar approach to identify the potential location of the medial plantar nerve and thus mitigate the risk of iatrogenic injury.

Each harvesting zone yields specific advantages and disadvantages. Harvesting in zone 1 results in less morbidity due to less surgical trauma and decreased harvesting time, but has considerable disadvantages, such as providing a shorter graft length, creating a higher risk of neurovascular injury if distal transection is performed blindly, and the inability to perform a tenodesis of the FHL remnant to the FDL. The benefits of harvesting in zone 2 are the ability to perform a tenodesis from the distal FHL remnant to the FDL and a longer graft length. However, harvesting in zone 2 will create further morbidity from a second medial incision along the foot with the possibility of neurovascular injury while dissecting near the neurovascular bundle at the knot of Henry. In turn, Zone 3 provides a much longer graft length and the possibility of augmentation, but requires three surgical incisions (even more surgical-related morbidity) and a longer surgery time. Moreover, some studies argue that great toe flexion stability for ground grip during stance gait has been a concern with the intermediate and long FHL harvest[8]. Despite the sacrifice of the primary hallux flexor, numerous investigations have demonstrated that the procedure typically results in preserved foot function with no significant deleterious effects on gait or daily activities[13,24-27].

The long FHL harvest technique provides longer grafts, and its potential remains unexplored. The extended harvest of the FHL provides a versatile source of autogenous tissue, suitable for the reconstruction of various tendinopathies, including those of the peroneal or tibialis anterior tendons[8].

Harvesting in zone 3 provides longer FHL grafts that are more appropriate for large Achilles defects, where an augmentation with the remaining FHL tendon may be needed. The distance between the base of the first metatarsal and the medial plantar nerve can serve as an important landmark in the plantar approach to identify the potential location of the medial plantar nerve and thus mitigate the risk of iatrogenic injury.

The present study has several limitations. The number of the cadaveric specimens was limited to those available for examination. Measurements were only accomplished by one assessor at one time, precluding the computation of intra- and inter-rater reliability; notwithstanding, all measures were made with utmost caution to avoid any inconsistencies.

The relative stiffness of frozen-thawed tendons may affect graft elongation and retrieval. Additionally, the restricted articular mobility characteristic of cadaveric models may not precisely simulate the dynamic plantarflexion observed in clinical practice, potentially affecting the reported harvesting dimensions. Lastly, variation in the distal transection site may have influenced the final graft length obtained.

Conclusion

The short harvest provided FHL grafts that covered a mean of only 48.5% of the calcaneal tunnel. The long harvest provides longer FHL grafts, which are more suitable for large Achilles defects, where an augmentation with the remaining FHL tendon may be needed. The distance between the base of the first metatarsal and the medial plantar nerve can guide orthopedic surgeons to avoid plantar nerve iatrogenic injury during intermediate FHL harvesting.

Authors' contributions: Each author contributed individually and significantly to the development of this article: DABS *(https://orcid.org/0000-0001-7005-896X) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, performed the surgeries, data collection, statistical analysis, bibliographic review and formatting of the article; MFZL *(https://orcid.org/0000-0002-9434-9961) Interpreted the results of the study, participated in the review process, performed the surgeries, data collection, statistical analysis; RA *(https://orcid.org/0000-0002-7636-7816) Data collection, statistical analysis, bibliographic review and formatting of the article; TDS *(https://orcid.org/0000-0001-9576-8351) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process and formatting of the article; XMO *(https://orcid.org/0000-0003-2231-0678) Conceived and planned the activities that led to the study, interpreted the results of the study, 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

Epidemiology, costs, and management trends of lateral ankle ligament injury

Christina Hermanns[1], Reed Coda[1], William M. Messamore[1], Matthew L. Vopat[2], Brandon L. Morris[1], Armin Tarakemeh, BA[1], Ravali Reddy[2], John Paul Schroeppel[1], Scott Mullen[1], Bryan G. Vopat[1]

1. University of Kansas Medical Center, Kansas City, KS, USA.
2. University of Kansas Medical Center, Wichita, KS, USA.

Abstract

Objective: This study primarily aimed to determine the incidence of patients diagnosed with lateral ankle sprain who ultimately progressed to operative treatment. Secondary study aims included determining the implementation and costs of physical therapy (PT), ankle bracing, and NSAIDs generated by the treatment of an ankle sprain diagnosis.

Methods: Data were collected using the Pearl Diver Humana dataset using ICD-9, ICD-10, and CPT codes pertaining to ankle sprain, ligament repair or reconstruction, physical therapy, ankle brace, and NSAIDs. Patients were categorized into nonoperative treatment, operative repair, and operative reconstruction. Incidence, cost, and PT attendance were compared among the three groups.

Results: A total of 309,670 patients who sustained a lateral ankle sprain between 2007 and 2017 were identified. Of the patients, 306,180 (99%; 306,180/309,670) completed nonoperative management, and 2,774 (1%; 2,774/309,670) underwent operative intervention. Of the nonoperative management patients, 63,276 (21%; 63,276/306,180) received PT. Of the operative management patients, 1,536 (55%; 1,536/2,774) received PT pre-operatively and/or post-operatively. The mean total cost was $923.32 for nonoperative management, $3,384.63 for operative repair, and $3,659.98 for operative reconstruction.

Conclusions: Within orthopedics, there are different treatments for lateral ankle ligament sprains. This study demonstrates that most patients with lateral ankle ligament sprains do not require operative intervention, as 99% of patients completed nonoperative management. Patients treated nonoperatively attended fewer PT visits and generated lower costs than patients who underwent operative repair or reconstruction. Only 20% of nonoperative patients received PT.

Level of evidence III; Retrospective observational cohort study.

Keywords: Ankle; Sprain; Cost; Epidemiology; Injury.

Introduction

Lateral ankle sprains represent one of the most common musculoskeletal injuries in the general and athletic populations[1-4]. A previous study looking at the epidemiology of ankle sprains in the United States found that ankle sprains occurred at a rate of 2.5 per 1,000 person-years, with nearly half occurring during athletic activities[5]. Most patients will recover through conservative treatment. However, some patients progressively develop chronic ankle instability, defined as persistent lateral ankle instability and pain for over six months[2,4,6,7].

Additionally, it is important to consider that patients with a history of a single ankle sprain are at higher risk of sustaining a future sprain, as sprains often recur[8]. Lateral ankle ligament injury has been shown to have a high socioeconomic burden not only due to injury frequency but also the chronic sequelae associated with an ankle injury, including long-term health consequences[4,7,9,10]. Chronic lateral ankle instability may

Study performed at the Department of Orthopedic and Sports Medicine at the University of Kansas Medical Center, Kansas City, KS, USA.

Correspondence: Ravali Reddy. 1151 N Pinecrest St. Wichita, KS 67208, USA. **Email:** rreddy3@kumc.edu. **Conflicts of interest**: none. **Source of funding:** none. **Date received:** February 3, 2026. **Date accepted:** March 22, 2026.

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result in laxity, chronic pain, early-onset ankle osteoarthritis, and, ultimately, decreased quality of life[9]. Operative treatment to restore ankle stability is indicated for patients who have chronic lateral ankle instability with a failure to respond to conservative treatment[11]. Although operative treatment plays a role in the management of lateral ankle ligament injury, the percentage of patients who eventually progress to surgery for ankle instability is not well defined in the literature[6,12].

Physical therapy (PT) is frequently prescribed as a treatment for lateral ankle ligament injury[4]. Formal PT is implemented for nonoperatively-treated ankle sprains, and as part of a post-operative rehabilitation program in patients who undergo lateral ankle ligament stabilization to address chronic lateral ankle instability. While studies have demonstrated that patients benefit from supervised PT exercises, evidence exists that self-directed home rehabilitation programs are just as effective as supervised PT[4,13,14]. There is limited literature addressing the financial burden of PT services. A Cochrane review comparing treatments for lateral ligament complex ankle injuries concluded that the current literature does not adequately compare the two treatment methods for ankle sprains—nonoperative and operative. It was mentioned that relevant cost outcomes would be beneficial for comparing conservative versus operative treatment interventions[15].

The primary aim of this study is to determine the incidence of patients diagnosed with lateral ankle sprain who ultimately progressed to operative treatment—either ligament repair or reconstruction. Secondary study aims included determining the implementation and cost of PT generated by the treatment of an ankle sprain diagnosis. Similar measures were obtained regarding lateral ankle bracing and Nonsteroidal anti-inflammatory drugs (NSAIDs).

Methods

Data was collected using the Pearl Diver Humana dataset. International Classification of Diseases, Ninth Revision (ICD-9), International Classification of Diseases, Tenth Revision (ICD-10), and Current Procedural Terminology (CPT) were used to create and sort groups of clinical diagnoses. Due to the use of a de-identified dataset, Institutional Review Board (IRB) approval was not required.

The diagnosis of lateral ankle sprain was identified through ICD coding. Nonoperative and operatively treated patients were sorted according to CPT code. ICD and CPT codes are summarized in Table 1. Inclusion criteria for operative treatment of lateral ankle sprain included either lateral ankle ligament repair or ligament graft reconstruction. Exclusion criteria for operative treatment included a history of multiple ligamentous ankle operations or other concomitant ankle operations; patients with multiple operative repairs or reconstructions were identified by repeated CPT codes. The percentage of ankle sprain patients who eventually underwent operative repair or reconstruction was calculated as the number of patients who underwent operative treatment divided by the total incidence of ankle sprain. Diagnostic costs associated with lateral ankle sprain were summed for the nonoperative and operative patient groups. Demographic data were collected for all patients to account for differences in gender, age, and geographical regions. ICD-10 codes for ankle sprains were also used to stratify results by injured ligament. Additionally, the incidence of multiple ankle sprains versus a single ankle sprain in the patient's history was assessed for each treatment group to evaluate its effect on treatment intervention.

Table 1. Patients with only one sprain code in the record versus multiple ICD sprain codes

Treatment	Single sprain	Multiple sprains
Nonoperative	207,896 (67.9%)	97,978 (32%)
Repair	215 (13.3%)	1,399 (87%)
Reconstruction	98 (9.3%)	956 (91%)

The prevalence of patients participating in PT before and after operative intervention was calculated, as well as PT participation after an isolated ankle sprain. The following criteria were used to classify incidence of patients participating in PT: Patients with CPT code(s) for PT in their medical record within one year of an ankle sprain diagnosis or lateral ankle ligament operation were included in the cohort classified as having received PT for their ankle injury, and patients who acquired CPT code(s) for PT within a year before their operation were classified as having received pre-operative PT. The purpose of these time-period limitations was to exclude any PT received for diagnoses unrelated to their ankle injury, which is irrelevant to this study and could inaccurately increase the calculated percentage of patients receiving PT for ankle injury. A patient's duration of PT participation was calculated as the time between the initial episode of the ankle sprain and/or surgical intervention (defined as the "event") and the last PT session in the patient's medical record. The duration of time was compared between groups to determine the length of the PT course for patients receiving nonoperative versus operative treatment for their lateral ankle sprain.

All patients were further sorted as those who received NSAIDs, durable medical equipment (DME) bracing, or neither during their treatment course to stratify the use of different conservative treatment modalities within each group. Another identified metric was patients who received PT in addition to another conservative treatment modality. To address the potential for a patient simultaneously using multiple nonoperative treatment modalities, an additional therapeutic aid (aside from PT) was excluded when comparing these metrics. For example, the assumption was made that patients within the NSAID group did not concomitantly wear a therapeutic brace.

Statistics analysis

ANOVA was performed to compare the mean days participating in PT after the event and the mean days from the event until a patient's last PT session across treatment groups. A post-hoc Tukey Honestly Significant Difference test was used to analyze the number of days between the event and the last PT that differed between groups. T-tests were used to compare the mean days in PT before and the mean days from first PT to the event for the repair and reconstruction groups. P-value was set at < 0.05 to be significant.

Results

A total of 309,670 patients with ICD codes for ankle sprains were identified in the Humana dataset. The demographic makeup of these patient populations, including gender, age, and geographical region, is outlined in Table 2. Use of a DME ankle brace, NSAID, and participation in PT are also reported in Table 2. Of the patients, 306,180 (99%; 306,180/309,670) did not have CPT codes for repair, reconstruction, or other operative ankle procedures and were subsequently classified as nonoperative patients. Additionally, 2,774 patients (1%; 2,774/309,670) had ICD codes for ankle sprain and subsequent CPT codes for ankle ligament repair or reconstruction. After excluding 106 patients (3.8%; 106/2,774) who underwent multiple ligament surgeries, 2,668 patients remained, having undergone one ankle reconstruction or repair. Of those who only underwent one ankle repair or reconstruction, 1,614 (60%; 1,614/2,668) patients remained in the ankle repair group, and 1,054 (40%; 1,054/2,668) remained in the reconstruction group. About 1% of patients with an ankle sprain ICD code eventually underwent operative ankle repair, and 0.3% eventually underwent operative ankle reconstruction. Overall, just under 1% (2,668/309,670) of the total ankle sprain population underwent ankle ligament repair or reconstruction operations. The operative group had a 60% higher prevalence of multiple sprains compared to the nonoperative group (Table 1). The ICD-10 codes for ankle ligament disruption or instability were used to determine relative estimates of the involvement of specific ankle ligaments in an ankle sprain (Table 3).

About 21% (63,276/305,879) of patients received PT in the nonoperative group, while a mean of 55% received PT after operative repair or reconstruction. Among the operative group, a lower percentage of patients underwent operative repair and had PT before their operation, after their operation, and in the group that had PT both before and after their operation. The mean number of sessions of PT per patient in the nonoperative group was 11 days, and the median time between the initial sprain diagnosis and the last day of PT was 139 days. In the operative repair group, the mean number of PT sessions before the operation was 7 days per patient, and after the procedure, it was 11 days per patient. The

Table 3. Code ligament percentages

Code	Total number of codes	% of total ICD-10 codes
Unspecified ankle ligament	36,684	69%
Calcaneofibular ligament	4,152	8%
Sprained ankle ligament, other	8,622	16%
Other ankle instability	3,875	7%

Table 2. Overview of demographics

Nonoperative				Operative			
Number of patients							
306,180 (98.9%)				2,668 (0.8%)			
Gender							
Male		Female		Male		Female	
109,730 (35.8%)		196,458 (64.2%)		1,066 (39.9%)		1,591 (59.6%)	
Age							
<20	20-40	40-60	>60	<20	20-40	40-60	>60
54,365 (17.7%)	56,182 (18.3%)	74,005 (24.2%)	131,127 (42.8%)	230 (0.8%)	605 (22.6%)	939 (35.2%)	894 (33.5%)
Region							
MW	NE	South	West	MW	NE	South	West
77,149 (25.1%)	4,828 (1.57%)	197,956 (64.6%)	26,319 (8.5%)	733 (27.5%)	38 (1.4%)	1,539 (57.7%)	361 (13.5%)
Use of physical therapy after the event							
63,276 (20.6%)				1,466 (54.9%)			
Use of DME Braces							
17,278 (5.6%)				526 (19.7%)			
Use of NSAIDs							
63,428 (20.7%)				581 (21.8%)			

MW: Midwest; NE: Northeast. Note: The discrepancy in the total percentage of patients is due to some patients being excluded due to undergoing other ankle surgeries.

median time between procedure and the last day of PT was 53 days. In the reconstruction group, the mean number of PT sessions was 8 before the operation and 11 after. The median time between reconstruction operation and the last day of PT was 51 days (Table 4).

Statistical analysis of differences in physical therapy

The mean number of days from the event to the last PT was significantly different (F = 49.8644, p < 0.0001); nonoperative patients participated in 59 more days of PT than those in the repair group (95% CI: 41.93, 75.78) and about 51 more days than those in the reconstruction group (95% CI: 30.63, 71.34). No significant difference was identified between ligament repair and reconstruction. No significant difference was found between any groups (F = 0.1040, p = 0.9013) in days of PT after the injury event.

There was no significant difference in mean days in PT before repair or reconstruction (t = 0.6896, p = 0.4066). The mean number of days from the first PT to the event was also not significantly different between the two groups (t = 0.0722, p = 0.7882).

A total of 58,065 (19%; 58,065/305,874) nonoperative patients used NSAIDs during recovery compared to 235 (15%; 235/1,614) repair patients and 193 (18%; 193/1,054) reconstruction patients. Similarly, 12,120 (4%/305,874) nonoperative patients used DME Braces during recovery, along with 233 (14%; 233/1,614) repair patients and 145 (14%; 145/1,054) reconstruction patients. The median number of days until last PT for patients who received NSAIDs after was 164 for nonoperative and 56 and 49 for repair and reconstruction, respectively. The median days until last PT for patients who received braces was 71 for nonoperative and 50 for both operative groups. The mean PT days per patient for nonoperative patients using NSAIDS was 13.6, and for repair and reconstruction was 15 days each. The mean PT days for nonoperative patients using braces were 13, 14, and 12 days for repair and reconstruction, respectively (Table 5).

The mean diagnostic cost of an ankle sprain ICD code without PT or further procedures was $400.51. The mean cost of PT per patient for nonoperative patients was $1,488.71, while the mean cost of PT for a repair patient before operation was $632.08 and after operation was $1,029.25. These results are summarized in Table 6.

Table 4. Overview of physical therapy use

	Patients who got PT Before	Patients who got PT After	Mean days in PT before	Mean days in PT after	Median days from first PT to event	Median days from event to last PT
Nonoperative	-	63,276 (20.6%)	-	11.01	-	139
Repair	365 (22.6%)	868 (53.7%)	7.93	11.03	351	53
Reconstruction	304 (28.8%)	598 (56.7%)	8.46	11.21	391	51

Table 5. NSAID and bracing use between treatment groups

	Treatment group	Patients	Patients who also received PT	Median days until last PT	Mean PT days/patient
NSAIDS	Non-Op	58,065 (18.9%)	16,669	164	13.6
	Repair	235 (14.5%)	140	56	15.2
	Reconstruction	193 (18.3%)	124	49	15.9
DME Braces	Nonoperative	12,120 (3.9%)	4,977	71	13.4
	Repair	233 (14.4%)	158	50	13.7
	Reconstruction	145 (13.7%)	97	50	12.2
Neither	Nonoperative	230,713 (75.4%)	40,500	137	10.2
	Repair	789 (48.9%)	524	52	11.4
	Reconstruction	642 (60.9%)	338	54	11.6

Table 6. Diagnostic and physical therapy costs

Treatment	Diagnostic cost ($)	Physical therapy Before event: Cost per patient	Physical therapy After event: Cost per patient	Total cost per patient
Nonoperative	$400.51	-	$1,488.71	$1,889.22 with PT, $400.51 without PT
Repair	$2,149.55	$632.08	$1,029.25	$3,810.88
Reconstruction	$2,162.85	$637.05	$1,098.51	$3,898.41

Discussion

Only about 1% of patients with an ankle sprain diagnosis proceed to operative treatment. Our results provide insight into previously published literature indicating that nonoperative ankle sprain treatment could reliably resolve a patient's symptoms, depending on the severity of the clinical case[3]. With higher severity of ankle sprains, however, there are still a considerable number of patients who ultimately undergo operative intervention to stabilize their lateral ankle ligament complex and will incur the higher costs associated with their care. Additionally, despite the lower diagnostic costs of nonoperative care, the high prevalence of ankle sprains and the higher prevalence of nonoperative care versus operative care mean that there is still an appreciable economic cost of lateral ankle sprains nationwide. Our data also show that a small percentage of patients undergo multiple-ligament procedures (3% repeat repair, 5% repeat reconstruction), which could give insight into the success rate of operative repair and/or reflect the complexity associated with operative reconstruction. No conclusion can be drawn upon this, but it could be a focus of future study. Both operative treatment groups had a higher percentage of patients who sustained multiple nonoperative ankle sprains than the nonoperative treatment group (87% repair, 91% reconstruction versus 32% nonoperative). Considering that candidates for operative repair of lateral ankle ligaments generally have first failed a nonoperative treatment course[16], it is unclear whether this is related to the data collected, revealing a higher percentage of operative patients have a history of multiple sprains.

Demographically, more patients over age 40 received operative intervention, but there was little difference in the type of operative intervention between the 40-60 age range and the 60+ age group. Nonoperative management had its largest percentage of patients in the 60+ age group. Lee et al.[17] reviewed the role of age in foot and ankle operations and concluded that multiple other factors, such as medical history, physical condition, and ambulatory status, must be considered before determining whether a patient's age is a contraindication to operative treatment of the ankle. All three treatment groups had a higher percentage of female patients than male, which parallels the findings of a systematic review reporting that ankle sprains are generally more common in females[18]. Doherty et al.[18] reported that the risk of a female athlete to sprain the ankle versus a male per exposure was 13.6 versus 6.94 per 1,000 exposures. In this study, 64% of total patients with ankle sprains (operative and nonoperative) were female, while only 36% were male. The difference in ankle sprains warrants further investigation.

While some patients participate in formal PT for ankle sprain rehabilitation, most nonoperative patients recover without supervised therapy. In the operative repair and reconstruction patients, higher percentages (53% and 56%, respectively) receive PT than nonoperative patients (21%). In a systematic review by Feger et al.[19], supervised rehabilitation for ankle sprains improved by a more significant margin of subjective patient outcomes compared to self-directed rehabilitation. Feger et al.[19] also found that the cost-effectiveness of home versus supervised PT was an area of research opportunity. Rao et al.[20] reported that manual therapy resulted in more significant improvements in ankle pain and function than home exercise programs. Our study found that PT increased the cost of treatment for an ankle sprain nonoperatively by a mean of $1,488.71 and for operative patients by $1,063.88. Although PT increases the overall patient cost, if patients experience significantly more favorable outcomes, this cost may be justified. Nonoperative patients attended PT for a considerably extended period, although they did not receive significantly more PT sessions.

A higher percentage of operative patients used DME braces than nonoperative patients (14% repair, 14% reconstruction versus 4% nonoperative patients). Functional support, including braces, was found to be favorable for the treatment of both acute and chronic ankle sprains to help decrease episodes of instability[21]. NSAID use was similar between both operative and nonoperative groups (14.5%, 18.3% versus 18.9%). Conservative treatment of lateral ankle sprain included NSAID use, bracing, and PT[22].

Our study estimated the diagnostic costs of an ankle sprain to be $400.51. In a study conducted in the Netherlands, the average cost per ankle sprain—excluding medical equipment or further sequelae—was $403.52, a close match to the $420.55 cost per ICD code reported in this study[23]. Shah et al.[24] aimed to assess the cost of an ankle sprain by sampling patients from emergency room visits. They found the mean cost of an ankle sprain to be $1,029. Another study examined the total societal cost of joint sprains ($9,196) and ankle injuries ($11,925) but did not break down the costs by diagnosis[7]. Although the latter two studies show higher costs than this study, they failed to examine ankle sprains specifically and only the healthcare costs associated with them. In this study, the cost of PT substantially increased the overall cost for a nonoperative patient, totaling 79% of the total cost. For operative patients, PT accounted for approximately 44% of the patient's total cost, indicating that although it was still a substantial cost, the operation accounted for a higher proportion. The cost-effectiveness of ankle sprain treatment beyond the initial diagnosis is an area that requires further research[6].

Limitations

The most significant limitation of this study is that using an insurance database does not capture the entire scope of a patient's medical record. Many individuals likely do not seek care for a minor ankle sprain, or their charts may not accurately reflect the care they receive. There could also be variation in how different providers use CPT codes. Additionally, an insurance database captures only the costs billed to the patient's insurance, not the patient's out-of-pocket costs.

The ICD codes used are not specific to different grades of ankle sprains, nor do they accurately describe the ligaments involved. Therefore, it is challenging to correlate whether one group had a significantly greater degree of high-grade sprains than the other. However, we can infer that the operative group would have more high-grade sprains since higher-grade injuries have a higher likelihood to need additional treatment and operation[25]. Therefore, the nonoperative group may contain more patients who require less PT (or no PT) because they have only a minor grade I sprain. Finally, this study could not determine a patient's health status or whether they were an athlete. Both could be additional predictors of a patient's recovery from an ankle sprain. A major limitation of this study is that the economic impact could not be correlated with patient outcomes or recovery. Thus, further studies are needed to better account for these variables in relation to patient outcomes after ankle sprains.

Conclusions

This study demonstrates that most patients with lateral ankle ligament sprains do not progress to operative treatment. Females are more likely to sprain their ankle than males. Patients treated nonoperatively had fewer physical therapy visits per patient and generated lower costs than those treated operatively with a repair or reconstruction procedure. However, only 20% of nonoperative patients received PT, and only 26% had participated in PT before undergoing operative treatment. Future studies should focus on understanding the economic outcomes associated with the diagnosis and treatment of ankle sprains and their correlation with functional patient outcomes.

Authors' contributions: Each author contributed individually and significantly to the development of this article: CH *(https://orcid.org/0000-0001-5884-0027), RC *(https://orcid.org/0009-0007-1126-5193), WMM *(https://orcid.org/0000-0003-3991-7513) Were involved in conceiving and planning the activities that led to the paper and have interpreted the results achieved; BLM *(https://orcid.org/0000-0002-4518-4128), AT *(https://orcid.org/0000-0001-6803-6999) Were involved in planning the activities that led to the paper and reviewed successive versions of the reviewing process; MLV *(https://orcid.org/0000-0003-3362-1842) Were involved in conceiving and planning the activities that led to the paper, have interpreted the results achieved, and reviewed successive versions of the reviewing process; RR *(https://orcid.org/0000-0002-1176-9806) was involved in reviewing the successive versions and participated in the reviewing process; JPS *(https://orcid.org/0000-0002-0040-502X), SM *(https://orcid.org/0000-0001-5150-2658), BGV *(https://orcid.org/0000-0003-2647-2260) Were involved in planning the activities that led to the paper, reviewed successive versions of the reviewing process iD.

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Original Article

Epidemiological profile of orthopedic foot and ankle surgeries before and after the COVID-19 pandemic

Thaisa Assad Araújo[1], Antônio Manuel Pinto Júnior[1], Bruna Sanches Bezerra[1], Giuliana Pereira Gomes[2], Isadora Pereira Gomes[1], José Henrique São João Peres[3], Letícia Zaccaria Prates de Oliveira[1], Pedro Henrique Vieira Partata[4], Danilo Ryuko Cândido Nishikawa[5], Rui dos Santos Barroco[1]

1. Serviço de Ortopedia e Traumatologia, Hospital Mário Covas, Santo André, São Paulo, Brazil.
2. Serviço de Ortopedia e Traumatologia da Universidade de Taubaté - UNITAU, Taubaté, São Paulo, Brazil.
3. Serviço de Ortopedia e Traumatologia da Santa Casa de Ourinhos, Ourinhos, São Paulo, Brazil.
4. Serviço de Ortopedia e Traumatologia do Hospital Municipal Antônio Giglio, Osasco, São Paulo, Brazil.
5. Departamento de Cirurgia Ortopédica, Hospital Alemão Oswaldo Cruz, São Paulo, SP, Brazil.

Abstract

Objective: To analyze the epidemiological profile of orthopedic foot and ankle surgeries, comparing the volume and distribution of procedures performed in the pre- and post-COVID-19 pandemic.

Methods: This is an observational, retrospective, and descriptive study, with a quantitative approach, based on the analysis of institutional records of orthopedic foot and ankle surgeries performed between 2017 and 2023. The data were grouped into two periods: pre-pandemic (2017–2019) and post-pandemic (2021-2023), excluding 2020 because elective procedures were suspended following the World Health Organization's announcement of the COVID-19 pandemic.

Results: A total of 742 orthopedic foot and ankle surgeries were analyzed. Of the total, 649 procedures (87.4%) occurred in the pre-pandemic period and 93 (12.5%) in the post-pandemic period, corresponding to an 85.7% reduction in surgical volume. There was a sharp drop in 2021, followed by a partial recovery in 2022. Fractures remained the main surgical indication in both periods, while elective procedures, especially corrections of forefoot deformities, showed a disproportionate reduction in the post-pandemic period.

Conclusion: The COVID-19 pandemic significantly reduced orthopedic foot and ankle surgeries, with surgical activity remaining lower in the post-pandemic period than in the pre-pandemic period.

Level of Evidence IV; Retrospective observational study.

Keywords: Foot injuries; Ankle injuries; Orthopedic surgery; COVID-19.

Introduction

Orthopedic conditions affecting the foot and ankle are a major cause of morbidity, functional limitations, and socio-economic impact, as this anatomical region is fundamental to ambulation and an individual's autonomy. Fractures, structural deformities, ligament injuries, and degenerative pathologies are among the main indications of specialized care, often requiring surgical intervention. Recent studies reinforce that ankle fractures remain among the most prevalent musculoskeletal injuries in hospital services, with a high care burden[1].

In addition to traumatic conditions, elective foot and ankle surgeries, such as corrections of hallux valgus, arthrosis, and forefoot deformities, have a high prevalence and direct impact on quality of life. Contemporary evidence shows that these conditions are associated with population aging, increased life expectancy, and greater demand for procedures aimed at functional improvement and pain relief. Recent reviews

Study performed at the Hospital Mário Covas, Santo André, SP, Brazil.

Correspondence: Rui dos Santos Barroco. Rua Dr. Henrique Calderazzo, 321, Bairro Paraíso, 09190-610/615, Santo André, SP, Brazil. **E-mail:** ruibarroco@uol.com.br.
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highlight the relevance of these surgeries in the context of modern orthopedics and their growing demand within health systems[2].

The organization of health services plays a decisive role in timely access to specialized orthopedic surgeries. Under regular conditions, there is a balanced coexistence between urgent and elective procedures. However, health crisis situations can significantly alter this pattern. The COVID-19 pandemic has imposed unprecedented challenges on health systems worldwide, resulting in the suspension or postponement of elective surgeries and the prioritization of emergency care[3].

In orthopedics, several studies published after the onset of the pandemic showed a significant reduction in surgical volume, including foot and ankle procedures. Recent literature indicates that, although trauma surgeries were partially maintained, there was a sharp drop in elective procedures, with a direct impact on the epidemiological profile of surgeries performed during this period[4].

Even after easing the restrictive measures, the recovery of surgical activity was gradual and heterogeneous. More recent studies indicate that the deferral of elective surgeries and the reorganization of care flows continued to affect procedure volumes in the years following the pandemic's critical phase. Comparative analysis between pre- and post-pandemic periods has been widely used as a methodological strategy to assess the lasting effects of COVID-19 on specialized orthopedic care[5].

Given this context, the objective of this study is to analyze the epidemiological profile of orthopedic foot and ankle surgeries performed in a reference hospital, comparing the volume and distribution of procedures in the pre-pandemic (2017–2019) and post-pandemic (2021–2023) periods, to evaluate the impact of the COVID-19 pandemic on specialized surgical activity.

Methods

This is an observational, retrospective, and descriptive study with a quantitative approach, whose objective was to analyze the epidemiological profile of orthopedic foot and ankle surgeries performed in a reference hospital, comparing the pre- and post-COVID-19 pandemic periods.

The study population consisted of all patients undergoing orthopedic foot and ankle surgical procedures between January 2017 and December 2023. For analytical purposes, the data were grouped into two distinct periods: pre-pandemic (2017–2019) and post-pandemic (2021–2023), excluding 2020 because elective procedures were suspended following the World Health Organization's announcement of the COVID-19 pandemic[6]. The period corresponding to the return of face-to-face activities in São Paulo was defined as the post-pandemic period[7].

The variables analyzed included the absolute number of surgeries per year, the total procedure volume per period, and the distribution of the main surgical indications, with an emphasis on fractures and elective procedures. Data analysis was performed descriptively, by calculating absolute and relative frequencies, annual means, and percentage variations. For the comparison between the pre- and post-pandemic periods, absolute and relative differences in surgical volume were analyzed without applying inferential statistical tests.

The results were presented using tables and graphs, designed to show the temporal distribution and the comparison between the periods analyzed. The study followed the ethical principles of research with secondary data, ensuring the anonymity of information and the confidentiality of records, and that individual patient identification is not necessary.

Results

A total of 742 orthopedic foot and ankle surgeries were analyzed over the study period. Of this total, 649 procedures (87.4%) were performed in the pre-pandemic period (2017–2019), while only 93 procedures (12.5%) were performed in the post-pandemic period (2021–2023). The direct comparison between the periods showed an absolute reduction of 556 surgeries, corresponding to an 85.7% decrease in surgical volume in the post-pandemic period, indicating a significant reduction in orthopedic foot and ankle surgical activity (Figure 1).

During the pre-pandemic period, a high and stable surgical volume was observed, with all care capacity in use. In contrast, the post-pandemic period showed a marked reduction in surgical activity, with only 23 procedures performed in 2021, followed by a slight recovery in subsequent years, still far below pre-pandemic levels.

The annual distribution of surgeries by procedure type showed a predominance of trauma surgeries throughout

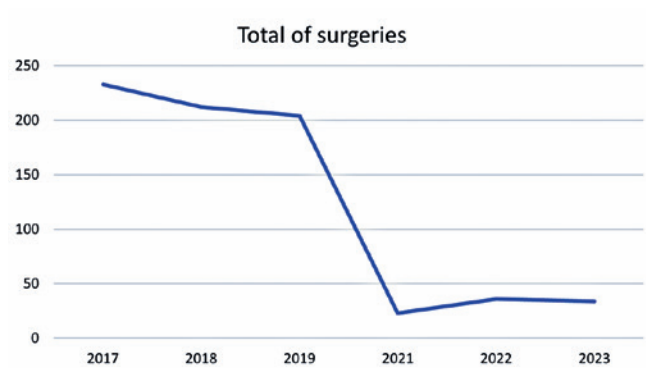

Figure 1. Number of surgeries per year: showing a significant reduction in surgical procedures, with stabilization in the post-pandemic period.

Note: Annual distribution of orthopedic foot and ankle surgeries between 2017 and 2023, showing a marked reduction in surgical volume in the post-pandemic period, with a more pronounced drop in 2021 and partial recovery in subsequent years.

the period analyzed. As shown in Figure 2, osteosyntheses accounted for the highest proportion of procedures across all years, with only slight variation between the pre- and post-pandemic periods. On the other hand, elective surgeries, especially hallux valgus corrections, showed a marked reduction in the post-pandemic period, with a more evident decrease in 2021 and partial recovery in subsequent years. Therefore, there was a change in the percentage composition of procedures, with a relative increase in the participation of trauma surgeries compared with electives in the post-pandemic period.

Regarding the epidemiological profile of surgical indications, foot and ankle fractures remained the main cause of intervention throughout the analyzed period, with less marked variation over the years, as shown in Figure 2. In contrast, elective surgeries, especially those aimed at correcting forefoot deformities, such as hallux valgus, showed a significant drop in the post-pandemic period, with a more pronounced reduction in 2021 and only partial recovery in subsequent years. This behavior shows a differentiated impact of the pandemic across procedure types, reflecting the prioritization of urgent cases and reduced assistance due to the restrictions imposed during the period.

Discussion

The results of this study demonstrate a significant reduction in orthopedic foot and ankle surgeries in the post-pandemic period, when comparing annual procedure means across the periods analyzed. This finding aligns with international evidence indicating that the COVID-19 pandemic was a determining factor in the reorganization of health services, with the prolonged suspension of elective surgeries and the prioritization of urgent cases, especially in orthopedics[8].

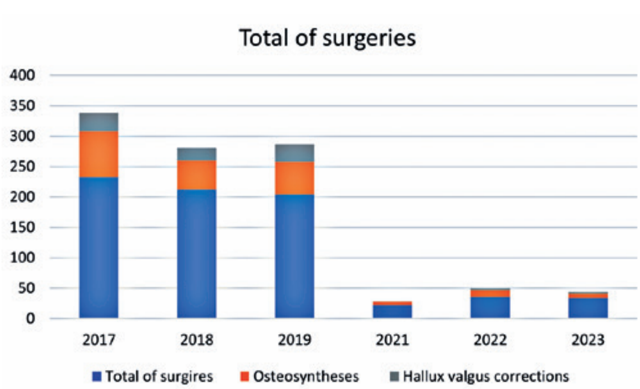

Figure 2. Surgeries analyzed per year, with emphasis on osteosyntheses and hallux valgus corrections.

Note: Annual distribution of orthopedic foot and ankle surgeries according to the type of procedure, highlighting the predominance of osteosyntheses over the period and the more pronounced reduction of elective surgeries, especially hallux valgus corrections, in the post-pandemic period.

The abrupt reduction observed in 2021 reflects the immediate impact of sanitary restrictions and the reallocation of hospital resources to face COVID-19. Multicenter studies have shown that, during the pandemic critical phase, orthopedic services operated with severely reduced capacity, maintaining predominantly trauma-related surgeries, while elective procedures were largely postponed[4]. This scenario is consistent with the profile observed in this study, in which fractures remained the primary surgical indication in the post-pandemic period.

The temporal analysis shows that even in 2023, the recovery in surgical volume was only partial, remaining far from pre-pandemic levels. This finding corroborates recent studies indicating a slow and heterogeneous recovery of orthopedic surgical activity, influenced by reduced demand, structural limitations, and the reorganization of care flows[9]. The persistence of this impact suggests that the effects of the pandemic extended beyond the health emergency period, prolonging access to specialized care.

Another relevant observation was the more pronounced reduction in elective surgeries, especially those aimed at correcting forefoot deformities, such as hallux valgus, as shown in Figure 2. These procedures showed a significant drop in the post-pandemic period, in contrast to trauma surgeries, which remained relatively stable throughout the period analyzed. This behavior suggests a differentiated impact of the pandemic according to the nature of the procedure, reflecting the prioritization of urgent cases and the temporary suspension of elective surgeries. This finding aligns with studies of the foot and ankle area, which demonstrate a greater impact on elective procedures during and after the pandemic, associated with both direct interruption and an increase in waiting lists, with clinical repercussions for patients previously indicated for surgery[10].

The maintenance of the predominance of fractures as the main surgical indication throughout the period analyzed reinforces the unavoidable nature of orthopedic trauma, even in contexts of health crisis. Recent evidence indicates that, although there was an overall reduction in traumatic visits during periods of confinement, foot and ankle fractures continued to require surgical intervention, especially those associated with instability or significant functional impairment[11].

From a health management perspective, the findings of this study highlight the importance of planning strategies to mitigate surgical complications in the post-pandemic period. Recent literature emphasizes the need to reorganize surgical schedules, expand operative capacity, and define clinical and functional criteria for prioritizing elective surgeries to reduce the prolonged impact on patients' quality of life and on health systems[12].

Finally, this study contributes to understanding the impact of the COVID-19 pandemic on specialized foot and ankle orthopedics in a Brazilian hospital setting, reinforcing international evidence and highlighting the relevance of comparative epidemiological analyses to support clinical and managerial decisions. The comparison between pre- and post-pandemic periods allows us to identify not only the magnitude of the reduction in care but also the persistent challenges to the full resumption of specialized surgical services.

Conclusion

The findings of the study confirm the hypothesis that the COVID-19 pandemic significantly affected orthopedic foot and ankle surgical activity, as evidenced by a significant reduction in procedure volume in the post-pandemic period compared with the pre-pandemic period.

Authors' contributions: Each author contributed individually and significantly to the development of this article: TAA *(https://orcid.org/0000-0002-3008-7) Data collection, and participated in the review process; AMPJ *(https://orcid.org/0009-0003-7549-1932) Conceived and planned the activities that led to the study, data collection, statistical analysis, wrote the article, and participated in the review process; BSB *(https://orcid.org/0000-0002-5382-5271) Survey of the medical records, interpreted the results of the study, and participated in the review process; GPG *(https://orcid.org/0009-0008-0728-9800) Bibliographic review, data collection, interpreted the results of the study, and participated in the review process; IPG *(https://orcid.org/0009-0009-8517-3448) Survey of the medical records, data collection, formatting of the article, and participated in the review process; JHSJP *(https://orcid.org/0009-0003-0543-230) Interpreted the results of the study, and participated in the review process; LZPO *(https://orcid.org/0000-0001-5849-5841) Interpreted the results of the study, participated in the review process, and formatting of the article; PHVP * (https://orcid.org/0009-0009-1529-0585) Statistical analysis, bibliographic review, interpreted the results of the study, and participated in the review process; RSB *(https://orcid.org/0000-0002-2870-2261), and DRCN *(https://orcid.org/0000-0003-0227-2440) Conceived and planned the activities that led to the study, supervised all stages of the study, interpreted the results of the study, and coordinated the review process. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID iD.

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Original Article

Müller-Weiss disease: epidemiology, surgical case series, and literature review

Isnar Moreira de Castro Júnior[1], Ana Carolina Lemos de Oliveira[1], Thomas Nogueira[1], Mariana Silva Gomes[1], Bruno Abdo Santana de Araújo[2], Henrique Mansur[2]

1. Instituto Nacional de Traumatologia e Ortopedia, INTO, Rio de Janeiro, RJ, Brazil.
2. Departamento de cirurgia ortopédica, IDOR, Distrito Federal, Brazil.

Abstract

Objective: To report a surgical case series, including the epidemiological profile and clinical and functional outcomes of patients with Müller-Weiss disease (MWD), thereby increasing knowledge of the pathology.

Method: Patients diagnosed with MWD who underwent surgical treatment between January 2010 and December 2021 were included in the study. Epidemiological information, comorbidities, reported symptoms, classification according to Maceira, surgical technique, time from symptom onset to surgery, and postoperative complications were recorded. Fisher's exact test was used to analyze the association between categorical variables, and odds ratios (ORs) were calculated with their respective 95% confidence intervals, with a significance level of 5% ($p < 0.05$).

Results: Forty-two patients (44 operated feet) with MWD were included in the sample, with a mean follow-up of 36.3 months. The mean age was 57.9 (± 9.4) years, and the body mass index was 32.2 (± 4.1) kg/m^2. There was a higher proportion of women (80.9%) and white patients (42.8%). The main comorbidity was systemic arterial hypertension (SAH), observed in 64.3% of cases, followed by obesity and type 2 diabetes (DM2), present in 59.5% and 14.3%, respectively. Pain was the main symptom, reported by 92.8% of patients. Maceira stage IV was the most prevalent (29.5%), and 57.1% of patients had bilateral involvement. The main procedures performed were isolated triple arthrodesis (34%), isolated talonavicular arthrodesis (22.7%), and talonavicular arthrodesis with calcanectomy (18.2%). Most patients (52.3%) underwent surgery within five years of symptom onset. After 12 months of surgery, 59.1% of patients reported residual pain, and 31.8% were reoperated on. Among these patients, patients with DM2 had a higher risk of chronic pain.

Conclusion: In this study, MWD presented a higher prevalence in female patients, white, over 50 years of age, hypertensive, and with obesity. Painful and bilateral presentation and diagnosis in advanced stages were observed in a large portion of cases. Triple arthrodesis was the most frequently performed procedure, followed by isolated talonavicular arthrodesis. One year after surgery, most patients reported residual pain, and this complication was more associated with the presence of DM.

Level of Evidence IV; Case Series.

Keywords: Orthopedics; Flatfoot; Treatment Outcome.

Introduction

Müller-Weiss Disease (MWD) is a complex orthopedic condition characterized by fragmentation and collapse of the navicular bone, with deformity and pain[1,2]. Previous studies have reported greater involvement in women aged 40 to 60 years, with bilateral involvement ranging from 40% to 75% of cases[3-5].

Its etiology is controversial, including combined theories of delayed ossification of the navicular and abnormal distribution of forces in the foot, as well as trauma, congenital dysplasia, and metabolic and autoimmune systemic diseases[1,2].

Several epidemiological scenarios that influence the development of MWD were identified, including childhood epidemic environmental stress, childhood nutritional stress,

Study performed at the Instituto Nacional de Traumatologia e Ortopedia, Rio de Janeiro, RJ, Brazil.

Correspondence: Ana Carolina Lemos de Oliveira. Av. Brasil, 500, Caju, 20940-070, Rio de Janeiro, RJ, Brazil. **Email:** anacarolina.ldo@gmail.com. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** February 2, 2026. **Date accepted:** April 12, 2026.

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foot deformities (metatarsal adduct and hindfoot varus), high-performance sports during childhood, and idiopathic involvement, in addition to the late/adult-onset of MWD. Although the first descriptions of MWD suggest that it is osteonecrosis of the navicular bone, histological studies have failed to confirm this initial hypothesis[1,6,7].

MWD presents as pain in the back of the foot, associated or not with ankle instability, and pain in the fibular tendons[8]. The medial longitudinal arch of the foot may be normal or reduced, associated with hindfoot varus deformity. The paradoxical flatfoot is characteristic of MWD and occurs in advanced stages of the disease, due to lateral collapse of the navicular and consequent lateral and plantar protrusion of the talar head, leading to subtalar joint varization. The inversion calcaneus, associated with plantar flexion of the talus, leads to worsening of hindfoot varus and adaptive external rotation of the tibia, thereby modifying the biomechanics of the lower limb[2,9].

Maceira and Rochera[8] reported five stages of the disease based on radiographs obtained in simple lateral incidence in orthostasis. The classification describes progressive changes with navicular fragmentation and associated deformities, such as plantar flexion of the talus and subtalar joint varus[1,2,10].

Although described as a rare disease, Monteagudo and Maceira[10] stated that the pathology is underdiagnosed, and several authors suggest that the prevalence may be higher than that reported[2,3]. In fact, there is a lack of epidemiological records and data in the literature to support indications and potential surgical methods for the treatment of MWD. The objective of this study is to report a surgical case series, including the epidemiological profile and clinical and functional outcomes of patients with MWD, thereby increasing knowledge of the pathology.

Methods

This retrospective longitudinal case series included patients diagnosed with MWD, aged 18 years or older, who underwent surgical treatment between January 2010 and December 2021 and had epidemiological data and complete pre- and postoperative radiographic follow-up in their medical records. Of the 68 patients initially identified, 17 were excluded due to incomplete epidemiological information in the medical record, and nine due to incomplete radiological study. The presence of comorbidities was not considered an exclusion criterion in this study. The final sample consisted of 42 patients, with two cases of bilateral involvement, totaling 44 feet, with a mean time between surgery and evaluation of 36.3 months (ranging from 3 - 99 months). The research was approved by the Institutional Review Board.

The diagnosis of MWD was made through physical and radiological examinations, including simple foot radiographs in anteroposterior and lateral views obtained in orthostasis, showing osteonecrosis of the navicular[2,8]. To define the epidemiological profile and the surgical outcomes presented, the following were evaluated: demographic information; complaints of joint pain and/or instability; presence of deformities; surgical technique employed; time between symptom onset and surgery; postoperative complications; and the need for reoperations. The severity of MWD was classified according to the classification proposed by Maceira[10].

Consolidation of less than 25% of the joint surface, as evaluated on simple radiographs three months after surgery, was established as a radiographic criterion for pseudarthrosis.

Data description was performed using absolute and relative frequencies, measures of central tendency, and dispersion. Fisher's exact test was used to analyze the association between categorical variables. Odds ratios (OR) were calculated with respective 95% confidence intervals, and a significance level of 5% ($p < 0.05$) was considered. Excel® 2016 version 1804 (16.0.9226.2156) was used to calculate the obtained data.

Results

The medical records of 42 operated patients diagnosed with MWD were reviewed; the cohort comprised 44 feet, 80.9% female, and 42.8% white. The mean age of the patients, based on the date of surgery, was 57.9 (± 9.4) years, and the body mass index (BMI) was 32.2 (± 4.1) kg/m^2. The main comorbidity reported was SAH, in 64.3% of cases, followed by obesity and type 2 diabetes (DM2), present in 59.5% and 14.3%, respectively. The main symptom reported was pain, in 92.8% of cases, with previous trauma reported in 30.9% of the sample. Of the 42 patients, 57.1% had bilateral involvement. According to the Maceira classification, among the 44 feet evaluated, stage IV was the most prevalent, with 13 cases (29.5%), followed by stages III and V, with nine cases each (Table 1).

Among the surgical procedures performed, the most frequent were triple arthrodesis in 15 cases (34%), calcaneal valgus osteotomy in 12 patients (27.3%), fixed with cannulated screws of 7.0 mm or kirchnner wires, and in eight cases osteotomy was associated with talonavicular arthrodesis, fixed with cannulated screws of 3.5 mm or 4.0 mm, and isolated talonavicular arthrodesis in 10 cases (22.7%) (Table 2) (Figures 1 and 2).

Most patients (52.3%) underwent surgery within five years of symptom onset. As acute postoperative complications, there was surgical wound dehiscence, one patient with skin necrosis, and one patient with pain due to prominence of the synthetic material in the talonavicular arthrodesis. There was no record of pseudarthrosis in our sample. After surgery, 26 patients (59.1%) reported residual pain; among them, patients with DM2 had a higher risk observed for this outcome (OR:10.0, p-value 0.10) (Table 3). And, 14 patients (31.8%) underwent new surgery, seven for synthetic material removal, and seven underwent arthrodesis (primary or new arthrodesis of the adjacent joint) (Table 4) (Figures 3 to 5).

Discussion

Studies investigating the outcomes of surgical treatment of patients with WMD are still scarce, largely due to misdiagnoses[1,2,8,10]. The main findings of this study were the predominance of female and white patients, a mean age of 57.9 years, and a BMI of 32.2 kg/m^2. The main comorbidities identified were SAH and obesity. Pain was the main complaint, present in 92.8% of patients, with bilateral involvement in 57.1% of cases. Maceira stage IV was the most prevalent

Table 1. Epidemiological data on patients with Müller-Weiss disease undergoing surgical treatment (n = 44 feet)

		n	%
Maceira classification	Stage I	6	13.6
	Stage II	7	15.9
	Stage III	9	20.4
	Stage IV	13	29.5
	Stage V	9	20.4
Sex	Female	34	80.9
	Male	8	19.1
Race/color	White	18	42.8
	Black	9	21.4
	Mixed race	15	35.7
Main complaint	Deformity	3	7.1
	Pain	35	83.3
	Pain, deformity	4	9.5
Side	Right	16	38.1
	Left	24	57.1
	Both	2	4.8
Time from symptom onset to surgery	Up to 5 years	24	54.5
	6 to 10 years	11	25
	≥ 11 years	9	20.4
Postoperative pain	Yes, less than 1 year	14	31.8
	No	18	40.9
	Yes, after 1 year	12	27.3
Reoperation	No	30	68.2
	Yes	14	31.8

Table 2. Surgical procedures performed in our sample (n = 44)

Procedures	n	%
Triple arthrodesis	15	34
Cacanectomy (Associated with talonavicular arthrodesis)	12 (8)	27.3 (18.2%)
Isolated talonavicular arthrodesis	10	22.7
Talonaviculocuneiform arthrodesis	3	7
Talonavicular and subtalar arthrodesis	3	7
Subtalar and calcaneocuboid arthrodesis	1	2

Figure 1. Preoperative radiographs of a patient with Müller-Weiss disease and symptomatic talonavicular and subtalar osteoarthrosis.

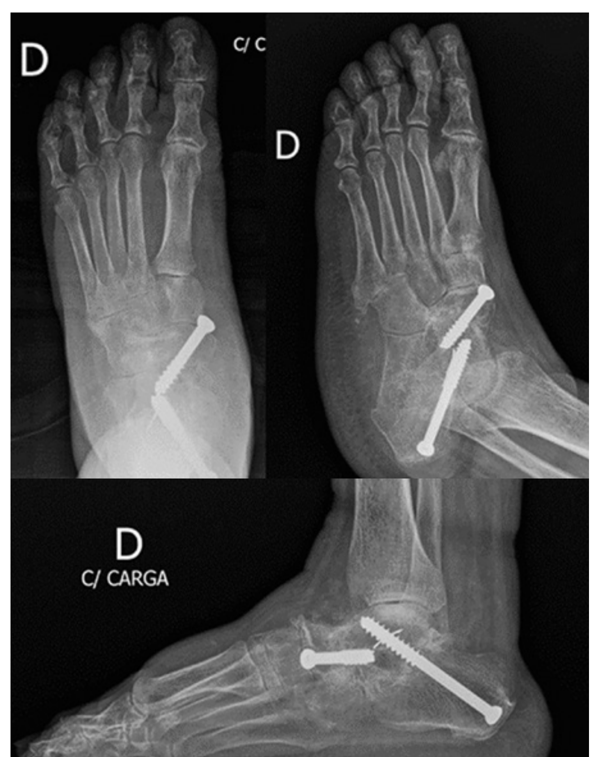

Figure 2. Radiographs of the same patient in Figure 1 showing the procedure used (talonavicular and subtalar arthrodesis with screws).

Table 3. Association between comorbidities and residual pain (n = 42)

Variable	Residual pain (n, %)	No pain (n, %)	OR (95% CI)	p-value
No comorbidities (n = 6)	2 (33.3%)	4 (66.7%)	1.00 (reference)	—
SAH (n = 27)	17 (63.0%)	10 (37.0%)	3.40 (0.54–21.2)	0.19
Obesity (n = 25)	17 (68.0%)	8 (32.0%)	4.25 (0.66–27.3)	0.14
DM2 (n = 6)	5 (83.3%)	1 (16.7%)	10.0 (0.64–15.6)	0.10
Smoking (n = 7)	5 (71.4%)	2 (28.6%)	5.00 (0.56–44.5)	0.15

OR: Odds ratio; CI: Confidence interval; SAH: Systemic arterial hypertension; DM: Diabetes mellitus. Reference group: Patients with no comorbidities. Fisher's exact test was used. P-values $p < 0.05$ are considered statistically significant.

Table 4. New arthrodesis procedures performed after one year

First procedure	Reoperation
Valgus osteotomy (2)	Triple arthrodesis
Osteotomy associated with talonavicular arthrodesis	Triple arthrodesis
Talonavicular arthrodesis	Associated with subtalar arthrodesis
Talonavicular arthrodesis (2)	Triple arthrodesis
Talonaviculocuneiform arthrodesis	Associated calcaneocuboid and intercuneiform arthrodesis

Figure 3. Preoperative radiographs of a patient with Müller-Weiss disease and symptomatic talonavicular arthrosis.

Figure 4. Radiographs of the same patient in Figure 3 showing the procedure used (talonavicular arthrodesis with two cannulated screws).

Figure 5. Radiographs of the same patient in Figures 3 and 4 that evolved to symptomatic subtalar arthrodesis. The reoperation was performed with subtalar arthrodesis with a cannulated screw.

(29.5% of cases). The most frequently performed procedures were triple arthrodesis and isolated talonavicular arthrodesis. One year after surgery, 59.1% of patients reported pain, and 31.8% underwent new surgery. Patients without comorbidities had a lower frequency of residual pain (33.3%). Finally, there was a progressive increase in the chance of residual pain in patients with DM2 (OR = 10.0), followed by smoking (OR = 5.0) and obesity (OR = 4.25).

A recent review study[11] demonstrated that WMD is more common in women, with greater bilateral involvement, especially between the fourth and sixth decades of life, and in individuals with high BMI. Our findings are consistent with what is most commonly reported in the literature. We observed 80.9% of female patients, bilateral involvement in 57.1%, a mean age of 57.9 years, and a predilection in patients with obesity (mean BMI 32.22 [± 4.15] kg/m^2). In addition, we noted that 42.8% of the individuals were white, and foot pain represented the main complaint, reported by 92.8% of the sample. The largest study on WMD was conducted by Maceira and Rochera[8], which described 191 cases. The author reported the association of WMD with external injuries and social and nutritional stress, related to the Civil War in Spain and the long period of poverty to which the population was exposed[8]. Subsequent studies did not report the same associations but described other factors related to osteonecrosis of the navicular, including diabetes, alcoholism, corticosteroid use, and metabolic disorders[12].

A previous study involving 16 patients with WMD reported SAH in 25% and diabetes in 18.7%[13]. In our study, we observed partially similar results. The main comorbidities identified were SAH (64.3%), obesity (59.5%), DM (16.7%), and smoking (14.3%). Previous authors[8] have highlighted the multifactorial theory, citing the rarity of cases observed with isolated predisposing factors. This idea reinforces the need to observe all clinical and epidemiological factors that may contribute to the development and progression of WMD.

Maceira and Rochera[8] described a staging system comprising five progressive degrees of deformity. Although there is no well-established clinical-radiological-prognostic relationship[1], radiological staging facilitates understanding of the anatomical changes present in the disease[12]. In our study, stage IV was the most prevalent, observed in 29.5% of cases. Of the total sample, 70.4% of patients were in advanced stages of Maceira (III to V), with the majority being symptomatic. Doyle et al.[3] published a study including 19 patients and reported that among the 12 symptomatic patients, 11 were between Maceira stages III and V. Other authors evaluated 36 symptomatic patients with WMD who underwent surgical treatment. Of these, 27 had Maceira stages III to V[14]. Our sample has a high rate of patients in advanced stages, possibly caused by the late diagnosis of WMD. In addition, our study is subject to selection bias, since only patients undergoing surgical treatment were included, which explains the low number of patients in the early stages of the disease.

The initial treatment of WMD is conservative and includes the use of anti-inflammatory drugs, orthoses, physiotherapy, and activity restriction[13]; however, unsatisfactory results are commonly reported[11]. Surgical treatment is the option in refractory cases, with the main objectives of achieving a plantigrade, aligned foot, restoring the height of the medial column, and improving pain[9,11]. Most patients indicated for surgical treatment are in Maceira stages III to V[11], similar to those found in our study. There is no established surgical gold standard for WMD[15], and each case should be analyzed individually based on the deformities. Among the numerous techniques described for the surgical treatment of WMD[9,10], the choice usually involves arthrodesis of the affected joints[9]. In our sample, only four patients did not initially undergo arthrodesis, and only calcanectomy was performed. However, two of them were later reoperated on with triple arthrodesis due to the persistence of symptoms. Isolated calcanectomy is indicated when there is poor varus alignment of the hindfoot[9] and has become the first surgical choice for Maceira and Monteagudo, regardless of the patient's radiographic stage[10]. Historically, surgical treatment with arthrodesis was directed at isolated fusion of the talonavicular or talonaviculocuneiform joint, but was associated with higher rates of pseudoarthrosis compared with triple arthrodesis[9,10]. In cases with more advanced degenerative changes in the subtalar and calcaneocuboid joints, triple arthrodesis presents more satisfactory results[9,10]. In accordance with the literature, triple arthrodesis was the most common procedure in our study, as most patients were already in advanced stages of the disease.

Among the possible complications after surgical treatment are infection, pseudarthrosis, symptomatic osteoarthritis in adjacent joints, and complications of the synthetic material and residual pain in the foot[16]. During postoperative follow-up of our patients, 14 reoperations were required, including skin debridement, removal of synthetic material, and new arthrodesis. Lu et al.[17], performed triple or talonavicular arthrodesis in 12 patients with advanced WMD (stage 3 or higher), with a mean follow-up of 16.8 months. They reported a significant improvement in AOFAS, ranging from 43.4 ± 16.1 to 85.3 ± 6.2 after one year postoperatively, with no cases of skin complications or pseudarthrosis. Ponz-Lueza et al.[18] reported three complications among the nine patients operated on in the study, including skin necrosis, posterior tibial pain, and sural nerve neuropathy. Postoperative pain occurred in 26 patients, representing 59.1% of the sample. Of these, 14 patients reported pain in the first postoperative year, and 14 patients (38.1%) needed to be reoperated. In our study, we observed a high rate of complications and reoperations, both recent and late, as well as the need for additional procedures. Despite the lack of statistical significance, DM showed the strongest association (OR 10.0), suggesting a possible independent effect on the outcome of residual pain. This finding is consistent with pathophysiological mechanisms related to microangiopathy and neuropathy resulting from the disease. Collectively, these data reinforce the importance of detailed and individualized preoperative planning that takes into account patients' personal factors, especially comorbidities, to avoid complications and future interventions.

There are several limitations in our study, including a small sample size, a retrospective design based on medical records, and the absence of functional evaluation of pre- and postoperative results, such as the AOFAS score or the visual analog scale of pain. Another limitation is the presence of multiple comorbidities and the use of various surgical techniques in our patients, factors that may have influenced clinical outcomes and reported complications. However, there is a shortage in the literature on the pathology, and further studies are needed to broaden the debate on WMD, especially its surgical treatment, which offers numerous options.

Conclusion

In this case series of patients with WMD undergoing surgical treatment, there was a predominance of females and white patients, aged over 50 years, hypertensive, and with obesity. With high frequency, the initial presentation occurred in advanced stages of the disease (Maceira stage IV), with pain as the main complaint and bilateral involvement in most cases. Surgical treatment with arthrodesis was the main therapeutic choice in the sample, with triple arthrodesis being the most frequently performed procedure. One year after surgery, 59.1% of patients reported pain, and the greatest association with the outcome of residual pain was with DM.

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Original Article

Antegrade screw fixation for reverse oblique fractures of the medial malleolus

Robinson Esteves Pires[1,2], Erick Veiga Franco da Rosa[1], Luis Fernando Delgado Trochez[1], Gustavo Waldolato Silva[1], Maria Laure Antunes Parreiras[1], Pedro Henrique Ribeiro Silveira[1], Vincenzo Giordano[3], Rodrigo Pesantez[4]

1. Hospital Felicio Rocho, Belo Horizonte, MG, Brazil.
2. Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brazil.
3. Hospital Miguel Couto, Rio de Janeiro, RJ, Brazil.
4. Fundación Santafé de Bogotá, Bogotá, Colombia.

Abstract

Objective: To assess the safety and effectiveness of antegrade minifragment lag screws in patients with reverse obliquity medial malleolar fractures.

Methods: A retrospective case series was conducted at a tertiary care institution between January 2019 and December 2024. Eligibility criteria included skeletally mature patients with reverse oblique medial malleolar fractures identified by radiographs and computed tomography, treated with antegrade minifragment screws. Functional outcomes were assessed using the AOFAS ankle-hindfoot score and the Olerud-Molander ankle score.

Results: Over the study period, two fellowship-trained orthopedic trauma surgeons performed 177 malleolar fracture fixations, of which 84 involved the medial malleolus. Six patients presented with the reverse oblique fracture configuration, all resulting from torsional trauma. All medial malleolar fractures achieved complete union without adverse events, with consolidation occurring within six weeks at the latest. After healing, no patient reported pain around the medial malleolus or implant-related discomfort.

Conclusion: The use of bicortical antegrade minifragment screws resulted in functional outcomes comparable to those described for standard fixation methods, without complications such as loss of reduction, nonunion, or malunion. Although the small sample size limits the external validity of the findings, the favorable results suggest that this technique may represent a viable alternative, especially in cases involving small fragments where bone preservation is essential.

Level of Evidence IV; Case Series.

Keywords: Ankle fractures; Fracture Fixation, Internal; Bone Screws.

Introduction

The incidence of ankle fractures is estimated at 112 to 187 per 100,000 people annually, with a rising trend observed in recent decades, particularly among aging populations[1,2]. Medial malleolar fractures account for approximately 32.5% of all ankle fractures and represent a clinical challenge due to their variability and implications for ankle stability[3-5].

Traditional classification systems, such as Herscovici et al.[6] and Pankovich[7], have been used to categorize medial malleolar fractures based on two-dimensional radiographs. However, beyond the AO/OTA[8] classification, these systems face limitations in terms of reproducibility and comprehensiveness, especially when applied to more complex configurations or uncommon variants, such as reverse obliquity fractures[9].

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

Correspondence: Robinson Esteves Pires. **Email:** robinsonestevespires@gmail.com. Avenida Alfredo Balena, 190, Santa Efigênia, 30130-100, Belo Horizonte, MG, Brazil. **Conflicts of interest**: none. **Source of funding:** none. **Date received:** March 17, 2026. **Date accepted:** April 12, 2026.

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Advancements in three-dimensional (3D) mapping have enabled detailed characterization of medial malleolar fractures, revealing recurrent patterns that assist in surgical planning and the selection of fixation methods[10-12]. These patterns highlight the high morphological variability of such fractures, emphasizing the need for precise and clinically relevant classification systems[9,10]. However, while the interesting classification systems describe transverse or oblique patterns, they fail to adequately address reverse obliquity patterns.

From the mechanical efficiency perspective, interfragmentary fixation achieves optimal stability and effectiveness when the lag screw is placed perpendicular to the fracture line. In this context, retrograde screw fixation may not be ideal in reverse oblique patterns, as it does not provide an adequate angle for perpendicular fracture fixation. Consequently, antegrade fixation emerges as a mechanically more promising fixation alternative[13,14].

This study aims to assess the safety and effectiveness of antegrade minifragment lag screws in patients with reverse obliquity medial malleolar fractures, thereby advancing therapeutic approaches for this often-overlooked condition.

Methods

This retrospective case series was conducted in a tertiary institution from January 2019 to December 2024. Ethical approval to conduct the study was obtained from the Institutional Review Board. The medical records of patients who underwent surgery for a displaced/unstable malleolar fracture were evaluated. The inclusion criteria consisted of skeletally mature patients with reverse oblique medial malleolar fracture patterns who underwent fixation with antegrade minifragment screws. The reverse oblique medial malleolar fracture pattern was defined based on the orientation of the fracture line in the coronal plane, as identified on both plain radiographs and computed tomography. Specifically, the fracture line was characterized by an obliquity opposite to that of typical medial malleolar fractures, extending in a reverse oblique direction. Patients with medial malleolar fractures who did not undergo fixation with the aforementioned technique were not included. Exclusion criteria comprised patients who did not meet the minimum six- month follow-up period or had incomplete imaging exams.

The functional outcomes were assessed using the American Orthopaedic Foot & Ankle Society (AOFAS) ankle-hindfoot score[15] and the Olerud-Molander ankle score[16]. Epidemiological data, fixation techniques, functional outcomes, follow-up duration, and complications were thoroughly assessed.

Complications were defined as loss of reduction, fracture-related infection, nonunion, malunion of the medial malleolus, and soft tissue necrosis requiring additional surgical intervention.

Antibiotic prophylaxis consisted of intravenous cefazolin (1 g every 8 hours) administered for 24 hours in all patients. Upon discharge, thromboprophylaxis for deep vein thrombosis was prescribed using either enoxaparin (40 mg subcutaneously daily) or apixaban (2.5 mg orally twice daily) for 35 days, according to surgeon preference.

In our series, the indication for temporary transarticular external fixation was primarily based on the inability to maintain adequate reduction of the fracture-dislocation after initial splint immobilization.

Results

From January 2019 to December 2024, two fellowship-trained orthopedic trauma surgeons performed 177 fixations of malleolar fractures in one tertiary institution. Among the sample of 177 malleolar fractures, 84 involved the medial malleolus, and six had a reverse obliquity pattern. Torsional trauma was the characteristic mechanism of injury in all six patients.

Table 1 provides the characteristics of the six patients with reverse obliquity fractures. Figures 1-6 illustrate the fixation strategy for medial malleolus fractures using antegrade minifragment screws.

A transarticular external fixator was applied in three patients. After the appearance of the wrinkle sign, patients underwent definitive open reduction internal fixation.

To illustrate the surgical technique and the evolution of treatment, we present two case examples below.

Patient 2

A 42-year-old woman sustained a torsional ankle injury and was diagnosed with an AO/OTA(8) 44B3 fracture of the left ankle (Figures 1 and 2). The soft tissues were in suitable condition for surgical fixation, and the patient underwent operative treatment eight days after the trauma. The procedure was conducted entirely in the prone position, thereby eliminating the need for intraoperative patient repositioning.

Table 1. Characteristics of the six patients presenting a reverse oblique medial malleolar fracture pattern.

Patient	Age	Sex	AO/OTA Classification	Fixation method
1	78	F	44-B3	1 antegrade minifragment screw (2.7 mm)
2	42	F	44-B3	1 antegrade minifragment screw (2.4 / 2.0 mm)
3	70	F	44-B3	2 antegrade minifragment screws (2.4 / 2.0 mm)
4	45	F	44-B3	2 antegrade minifragment screws (2.4 / 2.0 mm)
5	57	F	44-B2	1 antegrade minifragment screw (2.4 mm)
6	62	F	44-B3	1 antegrade minifragment screw (2.7 mm) + minifragment plate

F: Female.

Postoperative radiographs showed the quality of the reduction, and the patient was stimulated to move the operated ankle on the first day after surgery. Partial flat-foot weight-bearing in a boot was allowed as tolerated, and full weight-bearing was allowed after six weeks.

Figure 2 illustrates the range of motion after 12 weeks postoperatively.

Patient 3

A 70-year-old female patient presented with a torsional ankle trauma and sustained a fracture-dislocation of the right ankle (AO/OTA[8] 44B3) (Figures 3-5).

The patient was referred to our institution after eight days, presenting with significant edema and hemorrhagic blisters. A transarticular external fixation was initially applied due to poor soft-tissue conditions (Figure 3).

The patient was operated on 12 days after hospital admission, and the postoperative radiographs after six weeks show complete fracture healing.

Functional outcomes according to the AOFAS[15] and the Olerud-Molander[16] scores are presented in Table 2. Regarding complications, none of the patients with a reverse obliquity pattern experienced any of the aforementioned complications. All medial malleolar fractures healed uneventfully within a maximum period of six weeks. No patient reported medial perimalleolar pain or discomfort caused by the implants after fracture healing.

Figure 1. (A) Radiographs of the left ankle showing a trimalleolar ankle fracture. Observe the reverse oblique pattern of the medial malleolus. (B) Computed tomography scan in sagittal, axial, and 3D reconstruction of the left ankle showing a trimalleolar fracture.

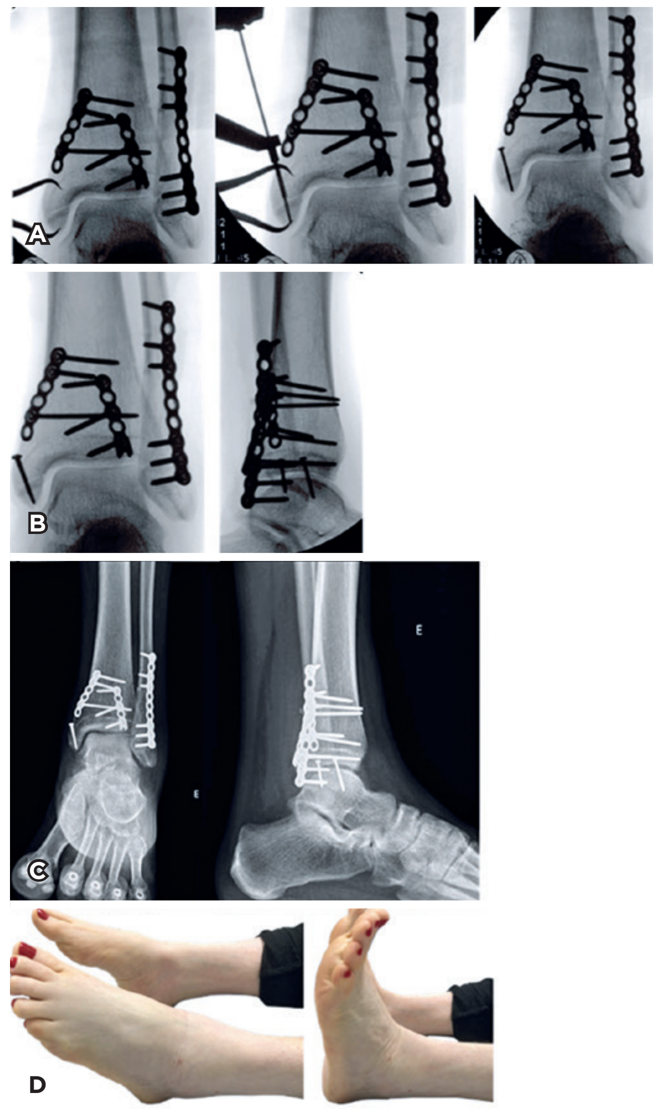

Figure 2. (A) Intraoperative fluoroscopic images showing fracture reduction and antegrade fixation of the medial malleolus using minifragment lag screws (2.4- and 2.0 mm screws). Observe the reverse obliquity of the medial malleolar fracture. (B) Postoperative fluoroscopy images in anteroposterior and lateral views showing fracture fixation using minifragment implants. (C) Postoperative radiographs after six weeks showing complete fracture healing. (D) Observe the symmetric range of motion of both ankles after 12 weeks postoperatively.

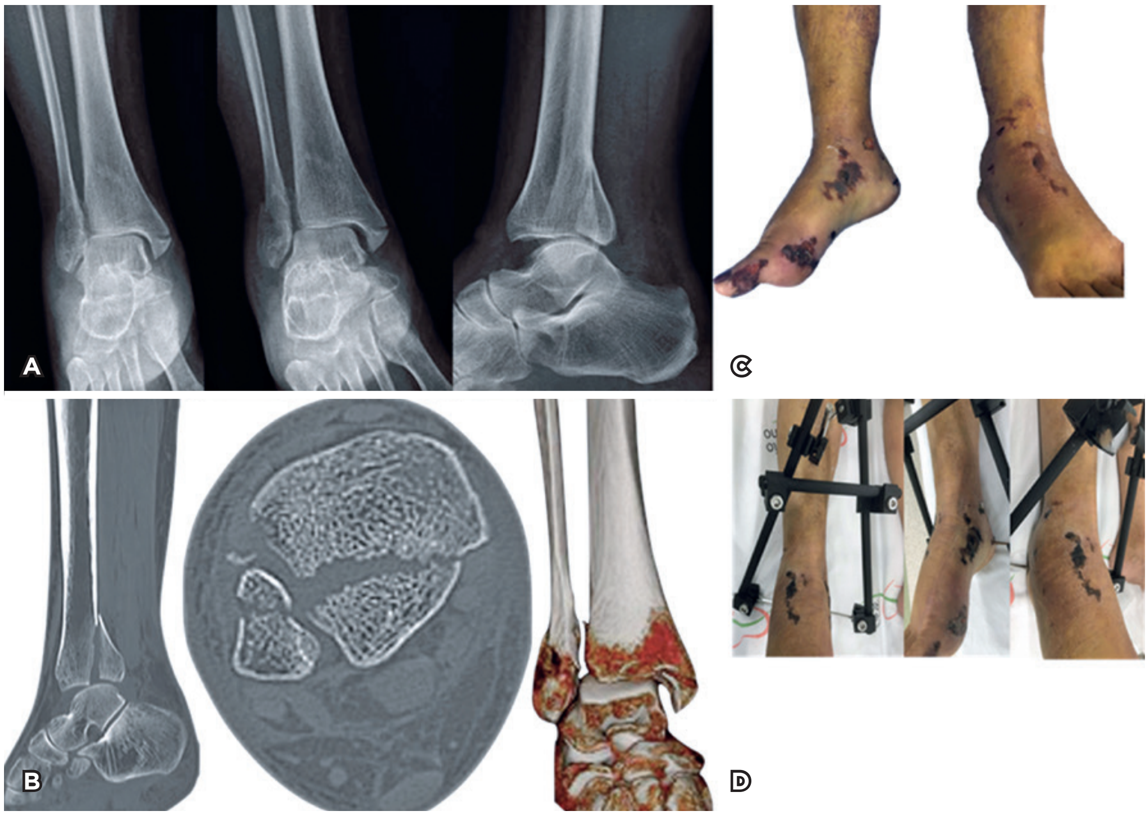

Figure 3. (A) Radiographs of the right ankle in anteroposterior and lateral views show the trimalleolar fracture-dislocation. Observe the reverse obliquity pattern of the medial malleolus. (B) Observe the sagittal, the axial, and the 3D reconstruction of the computed tomography scan showing the trimalleolar fracture dislocation. Observe the reverse oblique pattern of the medial malleolus. (C) Observe the clinical aspect of the right foot/ankle with edema and hemorragic blisters. (D) The right ankle was reduced and spanned. Note the presence of the wrinkle sign on the skin 12 days postoperatively, indicating improved soft tissue condition.

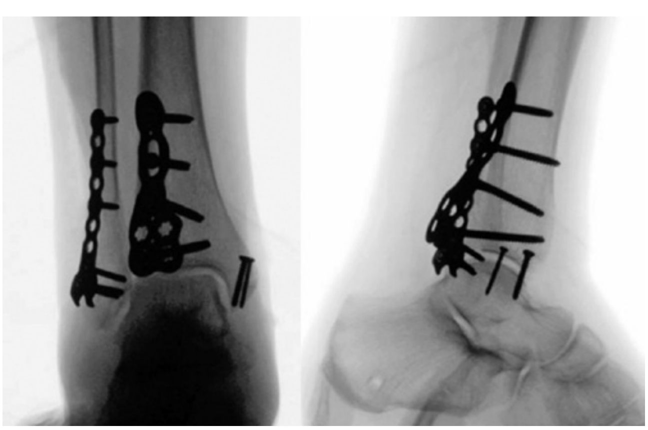

Figure 4. Observe the postoperative fluoroscopy images of the ankle showing fixation of the lateral malleolus with a 2.7 mm hook plate, fixation of the posterior malleolus with a 3.5 mm posterior plate, and fixation of the reverse oblique fracture of the medial malleolus with 2 antegrade minifragment screws (2.4 mm and 2.0 mm).

Figure 5. Radiographs of the right ankle in anteroposterior and lateral views showing complete fracture healing after eight weeks.

Figure 6. Illustration depicting the fixation of medial malleolar fractures using antegrade lag minifragment bicortical screws (A) and the standard retrograde screw technique (B). Note a potential complication associated with the retrograde screw technique in reverse oblique fractures. Due to compression, shearing forces may cause displacement of the fracture, as the compression is not perpendicular to the fracture line (C).

Table 2. AOFAS and Olerud-Molander scores

Patient	AOFAS[15] Total/100	Olerud-Molander[16] Total/100	Healing time (weeks)/ follow-up (months)	Complications
1	98	95	6/12	None
2	100	95	6/11	None
3	98	95	6/17	None
4	100	95	6/12	None
5	98	95	6/6	None
6	98	95	4 /7	None

AOFAS: The American Orthopaedic Foot & Ankle Society.

Discussion

In recent years, increasing attention has been directed toward the management of medial malleolar fractures. While the literature supports nonoperative treatment for undisplaced and minimally displaced fractures of the medial malleolus[17], a recent study reported that fixation of the medial malleolus in unstable ankle fractures, following fibular stabilization, was not superior to non-fixation in terms of primary outcomes[18]. However, one in five patients who underwent non-fixation exhibited radiographic nonunion. Despite the low reintervention rate to address this complication, the long-term implications remain uncertain. These findings suggest that selective non-fixation of anatomically reduced medial malleolar fractures may be appropriate after successful stabilization of the lateral malleolus. It is important to note that this debate primarily pertains to medial malleolar fractures that are anatomically reduced following lateral malleolar fixation, which represents a different clinical scenario from the displaced and unstable fracture pattern evaluated in the present study.

Several fixation methods are currently available for the management of medial malleolar fractures, including retrograde lag screws fixation (uni- or bicortical) using one or two screws (in parallel or divergent directions), headless screws, absorbable screws, combination of screw and K-wire, tension band wiring, modified tension bands, minifragment plates, and pre-contoured hook plates[19-31].

While the standard and most commonly used fixation method for medial malleolar fractures is open reduction and internal fixation with two lag screws, clinical and biomechanical studies in the literature also support fixation using a single screw[32,33].

However, the configuration of the fracture line in the coronal plane has received limited attention in the literature, despite the clear need for a more precise approach that optimizes interfragmentary compression by positioning screws perpendicular to the fracture line. In this context, Tekin et al.[13] and Chami et al.[14] reported favorable outcomes using headless antegrade screws to treat medial malleolar fractures with a reverse obliquity pattern.

Tekin et al.[13], in a study of 12 patients with a mean follow-up period of 17.2 ± 5.3 months (range, 12-23 months), reported that complete fracture union was achieved in all patients. The mean time to union was 3.4 ± 1.5 months (range, 2-5 months). No cases of instability, loss of reduction, nonunion, or infection were observed. The mean AOFAS[15] score was 95.0 (range, 87-99), with four patients showing good and eight achieving excellent outcomes. The mean time to return to the previous level of activity was 4.0 ± 2.5 months (range, 2-5 months). These findings suggest that anterograde headless cannulated screw fixation yields favorable clinical outcomes in the surgical treatment of Herscovici et al.[6] type B fractures.

Perhaps because of the limited literature on the treatment of medial malleolar fractures with antegrade screws, surgeons may be hesitant to adopt this fixation, given their unfamiliarity with the technique[34]. In this study, we employed bicortical minifragment screws (2.0, 2.4, or 2.7 mm) using the interfragmentary compression technique. Although, to our knowledge, there are no preclinical or clinical studies comparing these implants for the fixation of reverse oblique medial malleolus fractures, we chose bicortical cortical screws over headless compression screws. The choice of bicortical cortical screws over headless compression screws was deliberate and based on anatomical and biomechanical considerations. In small medial malleolar fragments, bicortical fixation may provide improved cortical purchase and greater construct stability. In the subcutaneous medial aspect of the ankle, the use of headless screws may still be associated with soft tissue irritation depending on implant positioning and fragment morphology. Bicortical screws also offer a readily available and technically straightforward option in most surgical settings. Additionally, the use of smaller-diameter screws would help preserve bone stock, as reverse obliquity fractures typically involve a small fragment. Despite this deviation from the standard technique, the functional outcomes were comparable to those previously reported in the literature, with no complications related to loss of reduction, nonunion, or malunion of the medial malleolar fractures.

Our study presents limitations. Firstly, the choice to use bicortical compression minifragment screws was based on the surgeons' preference rather than evidence. Secondly, the sample size was limited, making any comparative statistical analysis inadequate, as the study lacks the power for such evaluations. Thirdly, there was no control group using conventional techniques. Additionally, patient quality of life was not assessed, as only functional scores were used. The AOFAS ankle-hindfoot score, despite its widespread use, has recognized limitations in its clinimetric properties, including the lack of a fully patient-reported component and the inclusion of physician-assessed items. To mitigate this limitation, we also used the Olerud-Molander ankle score, a validated patient-reported outcome measure, to provide a more comprehensive functional assessment. A further limitation of this study is the heterogeneity in fixation technique, as one patient (Patient 6) required a different construct consisting of an antegrade minifragment screw combined with a minifragment plate. This variation, likely related to intraoperative factors such as fragment size or stability, may limit the series' internal consistency and should be considered when interpreting the overall results. Another limitation of this study is that all patients were female, which may limit the generalizability of the findings to a broader population. Given the small sample size, it is not possible to assert that the method used is reproducible or that similar outcomes would be achieved if the technique were applied in other centers.

However, some strengths should be highlighted. Despite the limited sample, this represents one of the largest case series on this topic in the literature. The modification of the technique using minifragment screws yielded functional outcomes comparable to those reported in similar studies, and no complications were observed. We believe that using minifragment screws is a promising alternative in such cases, as reverse obliquity fracture patterns involve small fragments and require techniques that preserve bone stock. Although the results are not supported by biomechanical studies, limited clinical observations suggest that reverse obliquity medial malleolar fractures should be safely and effectively fixed perpendicular to the fracture line rather than obliquely. This approach avoids unstable fixation or shear forces at the fracture site during interfragmentary compression (Figure 6).

Conclusion

This study highlights the challenges and opportunities in managing reverse oblique medial malleolar fractures. By utilizing bicortical minifragment screws via an antegrade approach, we achieved functional outcomes comparable to those reported with conventional techniques, with no observed complications such as loss of reduction, nonunion, or malunion. While our sample size limits the generalizability of these findings, the promising results suggest that this technique may be a viable alternative, particularly in cases with small fracture fragments where bone preservation is critical.

Author's contribution: Each author contributed individually and significantly to the development of this article: PRE *(https://orcid.org/0000-0002-3572-5576) Conceived and planned the activities that led to the study, participated in the review process, wrote the article, formatting of the article, and clinical examination; REVF*(https://orcid.org/0009-0003-1435-1311), SGW *(https://orcid.org/0000-0001-9330-4094), TLFD* PMLA *(https://orcid.org/0009-0006-9800-4422), SPHR *(https://orcid.org/0009-0008-6911-2234) interpreted the results of the study, participated in the review process, and clinical examination; GV *(https://orcid.org/0000-0002-4429-312X), PR *(https://orcid.org/0000-0002-5728-3115) interpreted the results of the study, wrote the article, and formatted the article. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) .

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Original Article

Safe and effective is not always acceptable: The case for PASS scores in foot and ankle orthopedic surgery

Nacime Salomao Barbachan Mansur[1,2], **Smitha Mathew**[1], **Jean Louka**[1], **Gregory P. Guyton**[1]

1. Department of Orthopedic Surgery, MedStar Union Memorial Hospital, Baltimore, Maryland, USA.
2. Department of Orthopedic and Traumatology, Paulista School of Medicine, Federal University of Sao Paulo, São Paulo, Brazil.

Abstract

Objective: To determine whether additional perspectives would be added to surgical reports in the foot and ankle literature by including outcomes for patient acceptable symptomatic state (PASS) (value beyond which the residual symptoms are felt to be acceptable) to minimum clinically important difference (MCID) outcomes (minimal amount of change that is felt to be clinically significant).

Methods: Visual analog scale (VAS) pain was chosen as a common, intuitively understandable patient-reported outcome for which PASS thresholds have been established in a variety of orthopedic conditions. A total of 21 consecutive studies in Foot and Ankle International from December 2020 to August 2022 that reported VAS scores before and after an intervention were included. Improvement beyond an MCID of 2/10 VAS pain was noted, and a 2/10 VAS PASS threshold was used. Subjective ratings of success were also extracted.

Results: All 21 studies reported improvement in VAS pain beyond the MCID, and 15 (71%) reported subjectively successful results. Based on a VAS PASS threshold of 2/10, successful results were observed in only 13 studies (62%).

Conclusion: Residual pain above the threshold that is acceptable to patients is frequently present in foot and ankle surgery, despite the common reporting of subjectively positive results. This demonstration illustrates that using PASS thresholds, in addition to improvement beyond an MCID, provides further context for determining successful surgical outcomes.

Level of evidence III; Retrospective Comparative Study.

Keywords: Patient Reported Outcome Measures; Ankle Joint; Pain.

Introduction

Clinical papers assessing patient-reported outcomes (PROs) typically determine success or failure based on the minimum clinically important difference (MCID) of the scale, the smallest change in an outcome's score that is of clinical value to patients[1]. This approach can demonstrate that an intervention has a measurable effect, but does not provide insight as to whether the patient is satisfied with their outcome. Recently, the patient acceptable symptomatic state (PASS) has been proposed as a threshold value of any PRO beyond which patients with a specific condition consider their outcome "acceptable"[2]. Philosophically, the approach can be summarized as "it is more important to feel good than to feel better." PASS data may represent an essential dimension of patient outcomes and supplement the use of the MCID for determining surgical success.

Study performed at the Department of Orthopedic Surgery, MedStar Union Memorial Hospital, Baltimore, Maryland, USA.

Correspondence: Nacime Salomao Barbachan Mansur. 3333 North Calvert Street, Suite 400, Baltimore, MD 21218, USA. **Email:** nacimesbm@gmail.com.
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In theory, a valid PASS threshold must be established for a specific PRO and pathology. This is accomplished by asking patients with that condition a global anchor question to determine whether their symptoms are acceptable and correlating the answer with their PRO outcome. One possible exception to this standard may be the visual analog scale (VAS) for pain, the simplest PRO. All papers that have formally calculated PASS thresholds for VAS pain in orthopedic conditions have reported values ranging from 14/100 to 30/100 (Table 1)[3-25]. This correlates with the intuitive point that patients seek final pain outcomes of less than 2 or 3/10[26]. Precedent exists to use a PASS threshold in the foot and ankle literature. Baumhauer et al.[27] used a pain value of 2/10 as the threshold of "significant" pain after autograft harvest for foot and ankle fusions.

As a demonstration of how the use of PASS thresholds may alter the interpretation of surgical results, we reexamined a sequential set of studies in Foot and Ankle International (FAI) that reported pre- and post-intervention VAS pain results and sought to answer the following questions:

1. Did the patients' VAS pain scores improve beyond the MCID?
2. Did the investigators subjectively rate the outcome as successful?
3. Did the patients' final VAS pain scores exceed a PASS threshold of 2?

Methods

Articles published in FAI from December 2020 to August 2022 were reviewed to identify studies reporting pre- and post-intervention VAS pain results after a therapeutic procedure. Four of the 25 papers identified were excluded because of inconsistent data reporting, leaving 21 studies for analysis (Table 2)[28-48]. If a study compared multiple interventions, the intervention interpreted as most favorable was used in the analysis.

The pre- and post-intervention VAS scores and the investigators' subjective descriptions of the intervention's efficacy were extracted. Surgical success was determined in three ways:

1. An intervention was considered successful by MCID criteria if the VAS pain score improved by more than 2/10 (or 20/100). This value is conservatively high in the range of MCIDs used for the scale in the orthopedic literature[26].
2. An intervention was considered successful by subjective criteria if the text included the descriptors of "reliable," "good," "effective," or "satisfactory."

Table 1. Orthopedic literature reporting MCID and PASS scores for VAS pain

Study	Subject	MCID value	PASS value	MCID reached	PASS reached
Abufoul et al.[3]	Rotator cuff	15	17	71%	48%
Allahabadi et al.[4]	Femoroacetabular syndrome	14.6	27.5	88.6%	70.9%
Ardebol et al.[5]	Glenohumeral arthritis	16	15	97%	78%
Beck et al.[6]	Femoroacetabular syndrome	14.8	21.6	97.6%	66.4%
Bilsel et al.[7]	Rotator cuff	14	30	100%	66.7%
Daniel et al.[8]	Anterior cruciate ligament	12	10	57.9%	79%
Fenn et al.[9]	Femoroacetabular syndrome	14.6	27.5	88.9%	60%
Ju et al.[10]	Femoroacetabular syndrome	15	19	76.9%	26.9%
Kunze et al.[11]	Femoroacetabular syndrome	21.6	21.6	89.7%	58.7%
Levins et al.[12]	Glenohumeral arthritis	21	15	89.7%	93.1%
Li et al.[13]	Cervical dizziness	25	30	82.5%	75%
Lu et al.[14]	Biceps tenodesis	12.9	27.4	73.3%	52.8%
Maldonado et al.[15]	Femoroacetabular syndrome	11	21.6	66%	71.7%
Menendez et al.[16]	Shoulder instability	17	25	61.1%	84%
Nakajima[17]	Achilles tendinopathy	10.6	14	100%	77.3%
Pasqualini et al.[18]	Adhesive capsulitis	11	20	98%	84%
Rice et al.[19]	Femoroacetabular syndrome	15.8	15.5	66.7%	56.8%
Rupp et al.[20]	Patellofemoral arthroplasty	24.6	25.5	54.4%	53.6%
Saks et al.[21]	Femoroacetabular syndrome	16.5	21.6	70.5%	58.3%
Scanaliato et al.[22]	Glenohumeral instability	11	30	97.3%	67.1%
Shao et al.[23]	Femoroacetabular syndrome	15	19	93.9%	48.5%
Yang et al.[24]	Femoroacetabular syndrome	15	19	83.8%	66.7%
Yokota et al.[25]	Knee osteoarthritis	14	30	55%	38%

MCID: Minimum clinically important difference; PASS: Patient acceptable symptomatic state; VAS: Visual analog scale

3. An intervention was considered successful based upon PASS criteria if the post-intervention VAS pain score was below 2/10 (or 20/100). This threshold was based upon the range of PASS scores found for VAS pain in previous orthopedic conditions (Table 1) and its previous use in the foot and ankle literature[27].

Results

The mean preoperative and postoperative VAS scores for the 21 included studies are shown in Figure 1. All 21 studies (100%) demonstrated improvement of VAS pain well beyond the MCID, 15 studies (71%) reported subjectively successful

Table 2. Studies in Foot and Ankle International 2020-2022 reporting VAS pain

No.	Article	No. patients	Follow-up	VAS		p-value
				Preoperative	Postoperative	
1	Del Vecchio et al.[32]	135	42.4 (30-66) months	7.9 ± 0.9	0.7 ± 0.9	< 0.001
2	Wang et al.[46]	32	56.9 ± 18.0 months	6.7 ± 0.9 (4-8)	2.3 ± 1.9 (0-8)	< 0.001
3	Amann et al.[29]	17 (20 feet)	15.87 (12-33) months	7.6 (4-9)	1.4 (0-4)	< 0.05
4	Yontar et al.[48]	77	35.5 (6-92, median 32) months	7.21 ± 1.08	2.21 ± 2.65	< 0.001
5	Fram et al.[34]	58	24 (12-33) months	64.5 (26.0)	26.8 (30.3)	0.001
6	Qin et al.[43]	43	28.23 ± 3.64 months (23-34)	4.38 ± 1.95	0.79 ± 1.06	< 0.1
7	Bahar et al.[30]	52	24 months	7.1 ± 1.1	0.4 ± 0.8	< 0.001
8	Kim et al.[38]	13	31 (24-60) months	7.3 ± 1 (95% CI, 6.7-7.9)	2.5 ± 1.5 (95% CI, 1.6-3.5;	< 0.05
9	Ferranti et al.[33]	27	26.5 (6-68) months	8.1 ± 0.9	2.4 ± 2.3	< 0.001
10	Greiner et al.[36]	42	32.8 (18-52) months	8.91 ± 1.0	1.47 ± 2.5	< 0.01
11	Piat et al.[42]	36	56 ± 36 (12-207) months	6.7 ± 2.4	2.3 ± 1.9	< 0.0001
12	Choi et al.[31]	42	31.8 (24-62) months	6.2 ± 2.1	1.1 ± 0.8	< 0.001
13	Neufeld et al.[41]	94	11.2 ± 4.4 (6-28) months	5.2 ± 2.4	1.6 ± 2.1	< 0.001
14	Scott et al.[45]	70	Minimum 1 year	7.5 ± 1.8	1.7 ± 2.2	< 0.0001
15	Garcia-Ortiz et al.[35]	29	3.4 (2-5) years	7.9 (2.5)	2.5 (2.7)	0.001
16	Hau et al.[37]	16	4.8 ± 0.91 years	60 (27)	16 (23)	< 0.001
17	Akoh et al.[28]	33	3.7 (1.0-9.8) years	4.8 (4.0-5.6)	0.2 (0.1-0.4)	< 0.001
18	Martin et al.[40]	93	19 (3-48) months	4.8 ± 1.5	1.3 ± 1.5	< 0.001
19	Yang et al.[47]	30 (43 joints)	28.2 (24-96) months	5.0 (4.2-5.9)	1.8 (1.2-2.5)	< 0.001
20	Li et al.[39]	7	17.4 (9-27) months	4.0 (2.0-5.0)	0 (0-1.0)	0.016
21	Rogero et al.[44]	81	58.9 (24-104) months	8.6 ± 1.2	3.7 ± 3.0	< 0.0001

VAS: Visual analog scale

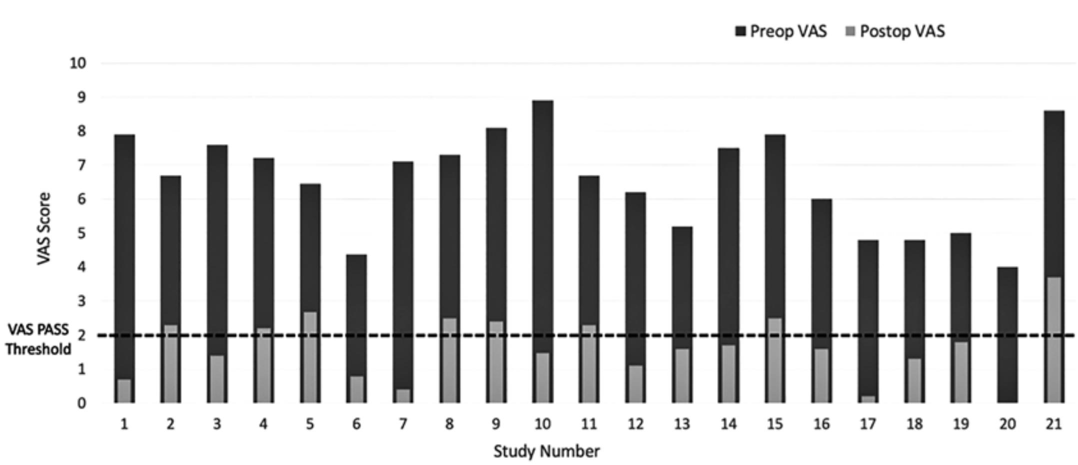

Figure 1. Preoperative and postoperative VAS pain in Foot and Ankle International studies. Preop: Preoperative; Postop: Postoperative; VAS: Visual analog pain scale. Broken line, VAS PASS threshold 2/10. See Table 2 for references.

results, and 13 studies (62%) reported final mean VAS pain scores below the chosen PASS threshold of 2 (Figure 2).

Discussion

Reaching a defined threshold in a PRO is a higher standard than simply demonstrating improvement. As in this analysis, it commonly results in a less satisfactory view of orthopedic interventions. Although many procedures result in improvement, patients commonly have residual pain and limitations.

PASS thresholds have gradually been established across a variety of orthopedic conditions for different PROs, including VAS pain. Nakajima[17] studied endoscopic debridement for Achilles insertional tendinopathy using the VAS MCID and a PASS threshold of 1.4. Although 100% of his sample reached MCID, only 77% achieved PASS. The 1.4 VAS value was obtained from a receiver operating curve (ROC) for "very satisfied" and "satisfied" states (area under curve [AUC]: 0.94). Similarly, using an ROC to determine the PASS threshold in patients who underwent an inlay patellofemoral arthroplasty, Rupp et al.[20] established a 2.55 threshold (AUC: 0.81) for VAS. In their sample, 53% reached this value, a rate similar to the rate who achieved the MCID for VAS (54%). After arthroscopic capsular release for adhesive capsulitis, Pasqualini et al.[18] obtained an MCID of 1.1 for VAS and a PASS threshold of 2 using distribution-based methods and ROC (AUC: 0.78), respectively. A total of 97% of patients achieved MCID, and 84% reached PASS. Using a distribution-based method for MCID and ROC method for PASS in VAS scores after hip arthroscopy for femoroacetabular impingement, Beck et al.[49] found that 98% achieved an MCID of 1.4 and only 66% achieved a PASS of 2.1.

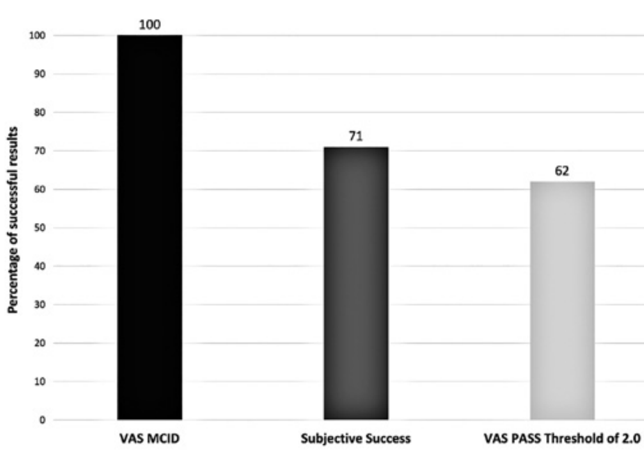

Figure 2. Percentage of successful results in the studied groups based on three different criteria. MCID: Minimum clinically important difference; PASS: Patient acceptable symptomatic state.

This study is best viewed as a demonstration of how surgical outcomes can vary depending on the standards used to define success. It is not a rigorous quantitative analysis. VAS pain was chosen for this demonstration because it is both intuitively understandable and backed by a body of literature across a variety of orthopedic conditions. It is far from a complete description of a patient's condition. Many other PROs can be used to assess function, strength, motion, and interference with activities. Nevertheless, the concepts of assessing outcomes using the MCID versus the PASS threshold are universal regardless of the rating scale used.

Surgical outcomes are complex, and the final level of satisfaction and relative improvement represent different facets of success. In more challenging conditions, such as a Charcot hindfoot, a limited outcome may be a reasonable expectation, even if the patient does not consider the final result acceptable. Patients may be less likely to find a limited outcome acceptable for simpler problems.

Conclusion

In this demonstration, PASS threshold analysis applied to VAS pain data from studies in the foot and ankle literature yielded a substantially more negative interpretation of pain outcomes compared with improvement beyond the MCID or subjective assessment. A more comprehensive picture of the outcomes of foot and ankle procedures and overall patient satisfaction can be gained by analyzing PROs in terms of both clinically relevant improvement (MCID) and the patient's acceptability of the final outcome (PASS).

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Original Article

Development and reliability of a device to measure medial longitudinal arch loading in individuals with foot pronation

Alícia Correa Brant[1], Isabela Lurdes Miranda Pereira[1], Fabrício Anício de Magalhães[2], Jéssica Pinheiro dos Santos[1], Larissa Aimée Assunção Alves[1], Ana Clara D'Villa Gonçalves Barbosa[1], Douglas Novaes Bonifácio[1], Emanuel Rodrigues Pinheiro[1], Henrique Silveira Costa[1], Renato Trede[1]

1. Federal University of the Jequitinhonha and Mucuri Valleys - UFVJM, Graduate Program in Rehabilitation and Functional Performance, Physical Therapy Department. Diamantina, MG, Brazil.
2. College of Education, Health, and Human Sciences, Department of Biomechanics, University of Nebraska at Omaha, University Drive South, Omaha, NE, USA.

Abstract

Objective: To develop the pronation loading (PL) device, evaluate its intra- and inter-rater reliability in single-leg stance, and investigate correlations between PL measures and gait kinetic and kinematic variables.

Methods: This cross-sectional study was conducted in two stages: (1) assessment of intra- and inter-rater reliability of the PL device, and (2) investigation of correlations between PL measurements and kinetic and kinematic gait variables. Reliability was analyzed using the intraclass correlation coefficient (ICC), and measurement error was assessed using the standard error of measurement (SEM) and minimal detectable change (MDC). Associations were evaluated using Pearson's correlation coefficient (r).

Results: Intra-rater reliability showed ICC of 0.75 and 0.73, with SEM ranging from 0.04 to 0.05. Inter-rater reliability demonstrated an ICC of 0.77, an SEM of approximately 0.04, and an MDC between 0.11 and 0.13. Pronation loading measurements showed moderate correlations with peak ankle evertor external moment, knee internal rotation moment, hip internal rotation moment, and hip adductor moment during gait.

Conclusion: The PL test demonstrated good reliability and significant associations with selected gait-kinetic variables, suggesting potential clinical applicability for assessing pronation-related loading during orthostatic standing.

Level of evidence III; Cross-sectional (two stages).

Keywords: Foot; Gait; Flatfoot; Kinematics; Pronation.

Introduction

Foot pronation plays a fundamental role in human gait mechanics[1]. Occurring primarily during the first half of stance, it contributes to energy dissipation through the foot structures[2]. As a triplanar motion, pronation involves calcaneal eversion, talar plantarflexion, and adduction, resulting in lowering and medial displacement of the navicular bone[3].

Excessive pronation may overload musculoskeletal structures and increase injury risk[4] and is associated with plantar fasciitis[5], posterior tibial tendinitis, and medial tibial stress syndrome[6]. Due to the oblique orientation of the subtalar joint, calcaneal eversion may be transferred proximally, promoting medial rotation of the leg and thigh[7,8].

Orthotic insoles are commonly used to support the medial longitudinal arch (MLA) and limit excessive pronation[9]. However, excessive correction may restrict the physiological pronation required for energy dissipation after initial contact[10,11]. Variable-density insoles produced by additive

Study performed at the Federal University of the Jequitinhonha and Mucuri Valleys (UFVJM), Diamantina, MG, Brazil.

Correspondence: Renato Guilherme Trede Filho. MGT-367 Highway, Km 583, 5000 - Alto da Jacuba - Diamantina, MG, 39100-000, Brazil. **E-mail:** trede@ufvjm.edu.br. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** March 16, 2026. **Date accepted:** April 02. 2026.

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manufacturing have emerged as a strategy to allow controlled pronation while maintaining biomechanical efficiency[12-14].

To optimize orthotic prescription, it is essential to quantify the force applied by the MLA to the ground in standing and determine whether this measurement relates to dynamic gait behavior. Therefore, this study describes the development of a device to assess medial longitudinal arch loading during single-leg stance, evaluates its intra- and inter-rater reliability, and investigates its association with gait kinematic and kinetic variables of the hip, knee, and ankle.

Methods

This cross-sectional study was divided into two stages. The first stage evaluated the intra- and inter-rater reliability of the device named pronation loading (PL), whereas the second stage investigated the association between PL measurements and gait kinetic and kinematic variables.

Participants were recruited from the physiotherapy teaching clinic at the Universidade Federal dos Vales do Jequitinhonha e Mucuri (UFVJM) through posters and social media. All volunteers provided written informed consent before the assessments. The research protocol was approved by the Institutional Review Board under the number CAAE 31685420.9.0000.5108.

Pronation loading

The PL consists of a digital tensile and compression dynamometer (Homis - MOD2100 - H004 - 557) with a load cell fixed inside a wooden box measuring 1 m × 1 m and 15 cm in height. At the top of the box, a piece of wood roughly the shape of the MLA is connected to the load cell by a screw, allowing the measurement of the applied direct force. The collected data, corresponding to the weight load on the MLA support, are displayed on an external digital display, with values presented in kilogram-force (kgf) (Figure 1).

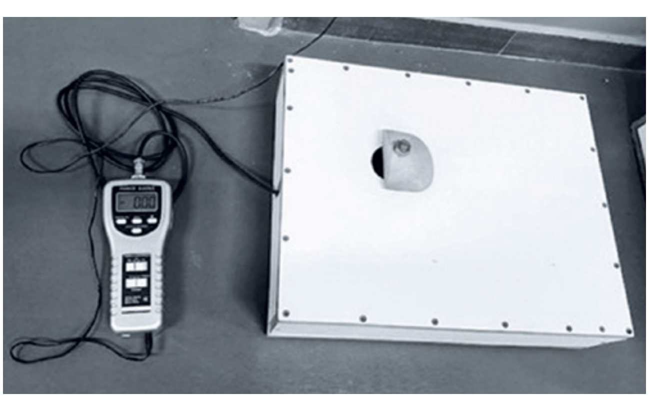

Figure 1. Pronation loading equipment.

Reliability

Participants

Individuals aged 18 to 45 years were included; they had no neurological or orthopedic diseases, had not undergone surgery on their lower limbs or spine, or used orthopedic insoles in the 12 months prior to data collection, and were able to remain in a single-leg stance for 10 minutes. Reports of pain or discomfort during data collection were considered exclusion criteria.

A sample size calculation was performed using G*Power software[15], based on Student's t-test, with statistical power set at 80% and a significance level of 0.05. The first data collection involved 39 volunteers, 10 (25.65%) men and 29 (74.35%) women. During the two days of data collection, we had a sample loss of 14 (35.90%) participants for various reasons, including travel, illness, and nonresponse. Therefore, 25 (64.10%) volunteers completed the evaluation on the second day of data collection, 5 (20%) men and 20 (80%) women, with a mean weight of 62.50 kg.

Procedures

Data collection was performed on the same day, in a laboratory, with the experimental conditions randomly assigned by lottery using an opaque envelope. The volunteers' structure and mass were measured. For the PL measurement, the volunteer was seated with the hip and knee joints flexed at 90 degrees and the ankle in a neutral position.

The foot was positioned on the wooden piece shaped like the MLA. The volunteer was asked to stand upright, extend the knee in a single-leg stance, and transfer all their body weight onto the apparatus for 5 seconds, simulating the midstance phase of gait. To avoid falls or instability, participants were allowed light fingertip support against a wall. This support was standardized across participants and limited to minimal contact to reduce its influence on load distribution. Only the dominant lower limb was assessed to standardize testing conditions and reduce variability associated with inter-limb differences. Although limb dominance may not directly reflect pronation characteristics, this approach was adopted to improve internal consistency.

Each measurement was repeated five times by two independent evaluators, and the mean value was used for analysis. After a seven-day interval, the same evaluators repeated the procedure to calculate the intraclass correlation coefficient (ICC).

Correlation with biomechanical variables

Participants

The sample size calculation for the correlation stage was performed using G*Power software[15], based on Student's t-test, with statistical power set at 80%, a significance level of 0.05, and a moderate effect size derived from a previous study[16].

The sample consisted of adults aged 18 to 45 years with a body mass index (BMI) of less than 30 kg/m^2 and a foot posture index (FPI) score of ≥ +6[17]. Exclusion criteria included a history of fractures or surgical interventions in the lower limbs within the last year, as well as pain or disability during the performance of the tests[15,16].

In total, 18 women (75%) and six men (25%) completed the study. Table 1 presents the demographic characteristics of the participants, indicating a mean age of 22.50 years (SD = 4.25), a mean height of 167.22 cm (SD = 8.65), a mean body mass of 65.36 kg (SD = 10.62), and a mean BMI of 23.33 (SD = 2.76) (Table 1).

Procedures

Initially, the FPI test was performed to determine sample inclusion. Following this, PL was collected, as previously described. To obtain the kinetic and kinematic variables of the ankle, knee, and hip in the coronal and transverse planes during gait, a three-dimensional (3D) motion capture system with nine cameras (Oqus 3+, Qualisys Medical AB, Gothenburg, Sweden) operating at a frequency of 200 Hz was used, synchronized with three FP 4060-08 force platforms (Bertec, Columbus, Ohio, USA) at a frequency of 1000 Hz.

First, the cameras were positioned to cover the entire capture area, and the system was calibrated using a calibration stick to adjust the capture volume, scale, and coordinate origin. Subsequently, the force platforms were configured, leveled, and temporally synchronized with the motion capture system to ensure synchronized data acquisition. Before each session, the platforms were zeroed to eliminate deviations, and the synchronization was tested to ensure data consistency. Finally, anatomical markers were positioned on the participant's body so that the software could calculate biomechanical variables, such as joint angles and ground reaction forces, enabling a precise gait analysis.

Individual calibration involved the precise placement of anatomical markers at specific points on the body, such as joints and bone segments, to allow the capture system to accurately track 3D movement. Passive markers were attached to the lower limbs and pelvis, following the Calibrated Anatomical Systems Technique (CAST) protocol[18,19], as illustrated in Figure 2.

Table 1. Characteristics of the volunteers: correlation of pronation loading with gait variables (n = 24)

Features	Percentage	
Sex	18 women (75%)	6 men (25%)
	Mean (SD)	
Age (years)	22.50 (4.25)	
Height (cm)	167.22 (8.65)	
Mass (kg)	65.36 (10.62)	
BMI (kg/m^2)	23.33 (2.76)	

SD = standard deviation; cm = centimeters; kg = kilograms; BMI = Body Mass Index.

First, anatomical landmarks were identified, and markers were symmetrically placed, avoiding areas of excessive skin movement to minimize relative motion errors. Subsequently, a static test was performed to identify the participant's neutral posture, allowing the software to create a digital model of the body structure. This model was adjusted based on individual parameters such as joint alignment and body segment length. Finally, five strides were collected at a self-selected speed, while the 3D motion analysis system recorded the data.

Kinetic and kinematic data were processed and analyzed using Visual 3D software (C-motion, Inc., Rockville, USA). The marker trajectories and force data from the force platforms were filtered using fourth-order Butterworth low-pass filters, applying cutoff frequencies of 6 Hz for the marker trajectories and 25 Hz for the force data.

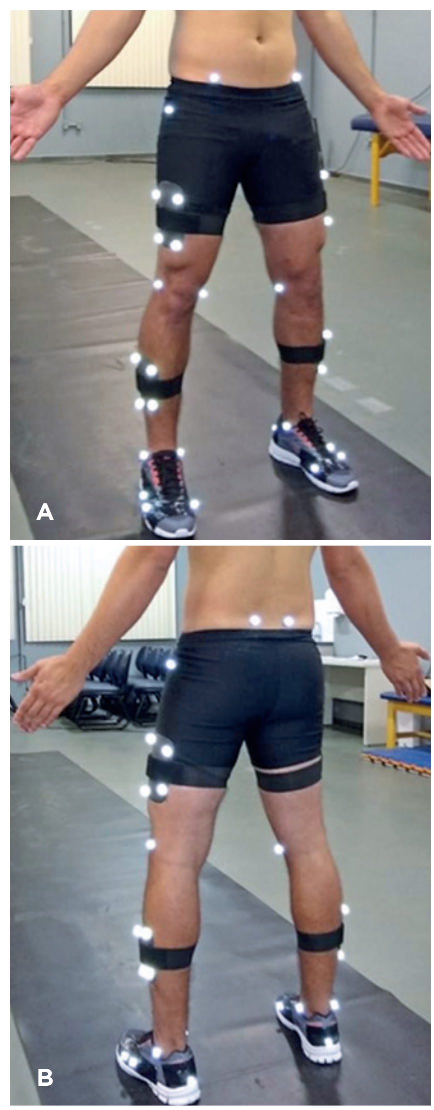

Figure 2. Passive markers of the lower limb segment.

Foot contact with the ground was automatically determined by the software, using the vertical component of the ground reaction force, with a threshold of 20 N. For each participant, the mean values across the five trials were used in the analysis, and all variables were normalized to a maximum of 101 points. The angular displacement of the hindfoot, knee, and hip was calculated in the coronal and transverse planes of the dominant lower limb.

Based on ground reaction force data, the inverse dynamics technique was applied to calculate the external force moments of the ankle, knee, and hip in the coronal and transverse planes. These moments were normalized to the volunteers' body mass and reported in units of Nm/kg to ensure comparability across participants.

Data analysis

To verify inter- and intra-examiner reliability, the ICC was applied. In addition, the standard error of measurement (SEM) was used to assess measurement accuracy, and the minimal detectable change (MDC) was used to determine the smallest detectable change.

Pearson's correlation coefficient (r) was used to assess the relationship between the PL measurements and kinematic and kinetic gait variables from the 3D motion analysis system. All statistical analyses were performed with a significance level of $\alpha = 0.05$.

Results

Pronation loading reliability

In the test-retest analysis, PL demonstrated satisfactory intra-rater reliability. The intra-rater ICC was 0.75 (95% CI: 0.60-0.84) in the first collection and 0.73 (95% CI: 0.58-0.83) in the second collection. The SEM was 0.04 (95% CI: -0.004-0.13) and 0.05 (95% CI: -0.04-0.14) on the respective days. These data are presented in Table 2.

Regarding examiner agreement, the instrument demonstrated good inter-rater reliability. The inter-rater ICC was 0.77 (95% CI: 0.63-0.85), with SEM of 0.04 (95% CI: -0.04-0.13) on the first day, and 0.77 (95% CI: 0.65-0.86) and SEM of 0.04 (95% CI: -0.04-0.12) on the second data collection. The variation in MDC was low[20], ranging from 0.11 to 0.13.

Correlation between pronation loading measurements and gait variables

The normalized mean PL value showed a weak positive correlation with peak ankle evertor external moment (r = 0.450; p = 0.027) and peak knee internal rotation moment (r = 0.427; p = 0.037). Additionally, significant correlations were observed with peak hip internal rotation (r = 0.586; p = 0.003), peak hip internal rotation moment (r = 0.583; p = 0.003), and peak hip adductor moment (r = -0.427; p = 0.039) (Table 3).

We found no correlation between PL and the variables peak ankle eversion (r = -0.209; p = 0.326); peak ankle abduction (r = -0.273; p = 0.196); peak ankle external adductor moment (r = -0.035; p = 0.872); peak knee adductor moment (r = -0.217; p = 0.309); peak hip adduction (r = -0.117) (p = 0.586); peak hip adductor moment (r = 0.050; p = 0.818) and peak hip external rotation moment (r = 0.137; p = 0.524).

Discussion

The aim of this study was to develop the PL device to quantitatively assess MLA loading, evaluate its intra- and inter-rater reliability, and investigate its association with gait variables in individuals with pronated feet.

Pronation loading reliability

Static tests, such as the PL, navicular drift test, and navicular drop test, can be predictive of MLA height during the mid-stance phase of gait. These weight-bearing tests reflect the inferior displacement of the navicular bone and MLA. In contrast, the supination resistance test (SRT), which involves elevating the navicular bone, can be performed either manually or with the supination resistance test machine (SRTM)[21]. This test is frequently used in clinical and research settings to estimate the force required to supinate the foot. All of these tests are easy to administer and low-cost, making them practical tools for clinical use.

This study investigated the reliability of PL and found good intra- and inter-rater reliability. The intra-rater ICCs were 0.75 and 0.73, and the inter-rater ICCs were 0.77 on both data collection days. Similar data were reported by Kirmizi et al.[22], who reported intra-rater ICC values of 0.93 and 0.97 for the navicular drop test, 0.72 and 0.85 for the navicular drift test, and 0.85 and 0.87 for the static and dynamic arc index,

Table 2. Test-retest measures of pronation loading (n = 25)

	Mean (SD)	ICC (95%CI)	SEM (95%CI)	MDC (95%CI)
Intra-rater 1	0.17 (0.07)	0.75 (0.60-0.84)	0.04 (-0.04-0.13)	0.12 (0.00-0.48)
Intra-rater 2	0.17 (0.07)	0.73 (0.58-0.83)	0.05 (-0.04-0.14)	0.13 (0.01-0.51)
Inter-rater 1	0.17 (0.07)	0.77 (0.63-0.85)	0.04 (-0.04-0.13)	0.12 (0.00-0.49)
Inter-rater 2	0.17 (0.07)	0.77 (0.65-0.86)	0.04 (-0.04-0.12)	0.11 (0.00-0.45)

Mean: refers to the combined mean values of days 1 and 2 for intra-rater or the combined mean values of examiners 1 and 2 for inter-rater (kgf). SD: Standard Deviation. 95% CI: 95% confidence interval. ICC: Intraclass Correlation Coefficient. SEM: Standard Error of Measurement. MDC: Minimal Detectable Change in the 95% CI. Intra-rater: measurements for the same examiner on two different days. Inter-rater: measurements for two different examiners on the same day.

Table 3. Pearson correlation of the normalized mean of pronation loading with biomechanical gait variables. (n = 24)

Gait variables	Pearson correlation	Normalized mean pronation loading
Ankle eversion peak	Pearson correlation	-0.209
	sign (2 limbs)	0.326
Peak external moment of ankle evertor	Pearson correlation	**0.450***
	sign (2 limbs)	0.027
Peak ankle abduction*	Pearson correlation	-0.273
	sign (2 limbs)	0.196
Peak external moment of ankle abductor*	Pearson correlation	-0.035
	sign (2 limbs)	0.872
Knee adductor peak	Pearson correlation	-0.217
	sign (2 limbs)	0.309
Peak moment of internal rotation of the knee	Pearson correlation	**0.427***
	sign (2 limbs)	0.037
Peak hip adduction	Pearson correlation	-0.117
	sign (2 limbs)	0.586
Peak hip adductor moment	Pearson correlation	0.050
	sign (2 limbs)	0.818
Peak hip adductor moment	Pearson correlation	**-0.425***
	sign (2 limbs)	0.039
Peak internal rotation of the hip	Pearson correlation	**0.586****
	sign (2 limbs)	0.003
Peak moment of external hip rotation	Pearson correlation	0.137
	sign (2 limbs)	0.524
Peak moment of internal hip rotation	Pearson correlation	**0.583****
	sign (2 limbs)	0.003

**The correlation is significant at 0.01 level (2 extremes). *The correlation is significant at 0.05 level (2 extremes).

respectively. Furthermore, the SRTM showed an intra-rater ICC of 0.89 and an inter-rater ICC of 0.78[21].

Although the same individual may exhibit high intra-subject variability in repeated measurements[23], in this study, the SEM ranged from 0.04 to 0.05, while the MDC ranged from 0.11 to 0.13. These results indicate low variation across repeated measurements, suggesting that PL is a reliable method for assessing forces related to foot pronation. In comparison, the SRT presented SEM values ranging from 7.3 to 9.0 and MDC values between 20.4 and 24.9[24], demonstrating greater measurement variability.

Correlation of pronation loading with 3D gait analysis

In our sample of individuals with flat feet, PL was positively correlated with peak ankle evertor external moment (r = 0.480), peak knee internal rotation moment (r = 0.427), peak hip internal rotation (r = 0.586), and peak hip internal rotation moment (r = 0.583). A negative correlation was also identified with the peak hip adductor moment (r = -0.427).

The positive correlation between PL and peak ankle evertor moment suggests that increased foot pronation is associated with greater lowering of the MLA, resulting in overload on structures responsible for ankle eversion. Previous studies indicate that increased rearfoot eversion during gait is characteristic of individuals with flat feet[25,26] and is associated with reduced MLA height[27]. Changes in the elastic behavior of the plantar fascia may contribute to gait abnormalities in these individuals[25] because increased MLA flexibility reduces the foot's ability to function as a rigid lever during push-off. This change results in reduced support for the gastrocnemius and soleus muscles, compromising gait effectiveness[28].

Excessive hindfoot pronation also influences internal tibial rotation, causing passive stress and altering the direction of forces on the patellofemoral joint[29]. A positive correlation was observed between PL and peak internal knee rotation, suggesting greater compression in medial knee structures and a higher propensity for patellofemoral pain syndrome. One proposed mechanism is that excessive foot pronation leads to internal rotation of the tibia and femur, resulting in a reduced contact area at the patellofemoral joint[30]. Excessive subtalar pronation has historically been identified as a dysfunctional biomechanical factor in the lower limbs, leading to adaptations in other joints[31]. Although conflicting evidence exists regarding the relationship between patello-femoral pain syndrome and ankle and foot deformities, such biomechanical changes must be carefully analyzed[32].

Finally, the coupled movement between the hindfoot and hip joints has already been reported in a previous study[33]. In the present study, we identified a positive correlation between PL and peak internal hip rotation, and a negative correlation with peak hip adductor moment. Reduced hip adductor torque, together with increased hip and knee internal rotation[34], reinforces the association between foot pronation and proximal rotational mechanics during walking. During the stance phase, increased hip adduction can be a strategy to elevate the MLA by shifting the load to the lateral side of the foot, thereby reducing the compressive force on the MLA[35]. The hip internal rotation moment demonstrated a biphasic pattern during the stance phase, with a first peak in early stance and a second peak in late stance. This pattern is consistent with previously reported normative gait data[36].

This study had several limitations. The PL showed substantial variation over the 5-second recording period, suggesting that a longer time may be needed for dynamometer stabilization. In addition, the potential influence of external support on weight transfer during testing cannot be entirely ruled out. Another important limitation is that the wooden support arch may not fully adapt to different foot morphologies and sizes, potentially influencing the measured load and affecting construct validity. Future designs should consider adjustable or customizable interfaces to improve anatomical conformity. Finally, the sample included a greater proportion of women than men. Despite these limitations, the device appears to be a reliable, low-cost, and easy-to-use tool with potential for clinical application.

Conclusion

The pronation loading test demonstrated good intra- and inter-rater reliability for assessing pronation-related loading in standing. In addition, PL measurements were significantly associated with selected gait kinetic variables, suggesting potential clinical applicability. However, further studies are needed to investigate additional measurement properties and to refine the device for different foot morphologies.

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Case Report

Infected talar malunion treated with fresh tibiotalar allograft: A case report

Paula Andrea Solano Dazzarol[1], Claudia Juliana Reyes[1]

1. Pontificia Universidad Javeriana, Bogota, Colombia.

Abstract

Talus fractures are rare injuries, with an incidence ranging from 0.1% to 0.85% of all fractures. Due to their complex anatomy and specific irrigation patterns, they pose a significant therapeutic challenge for orthopedic surgeons. The talus lacks muscle attachments, receives most of its irrigation through small terminal branches, and bears much of the hindfoot's loads, making it especially vulnerable to avascular necrosis, malunion, and other complications. We present a patient managed with a fresh tibiotalar autograft, with favorable short- and long-term outcomes.

Level of evidence: IV.

Keywords: Talus; Avascular necrosis; Allograft; Reconstruction; Malunion.

Introduction

Talus fractures are rare injuries, accounting for less than 1% of skeletal fractures. They are most often seen in young patients, predominantly men, after high-energy trauma mechanisms, such as traffic accidents or falls from heights[1]. The particular anatomical talus configuration, which articulates with the tibia, fibula, calcaneus, and scaphoid, together with its extensive cartilaginous coverage and the scarcity of muscle insertions, contributes to its delicate vascular supply[1].

The Hawkins classification, established in 1970, remains the reference for assessing vascular compromise. This author described four grades: type I (non-displaced fracture), type II (associated with subtalar joint subluxation), type III (displaced fracture with tibiofibular dislocation), and type IV (additional talonavicular joint dislocation)[2]. As the degree of displacement increases, the risk of avascular necrosis rises, reaching up to 90% in type III[2].

Complications following these fractures are common and include avascular necrosis, pseudoarthrosis, malunion, post-traumatic osteoarthritis, and varus or valgus deformities[3]. Talus avascular necrosis is the most feared, as it can trigger bone collapse and secondary osteoarthritis. Malunion, by contrast, is associated with alterations in joint congruence, progressive deformities, and significant functional deterioration. Its management involves complex reconstructive procedures aimed at restoring joint congruence and limb functionality[4].

Case presentation

A 23-year-old male patient with no significant pathological history, with a recent history of motorcycle vs. car traffic accident, as a motorcycle driver on 12/30/2022, with multiple fractures in the left lower limb; he presented a luxo-open fracture of the left talus, Hawkins classification type III, and an open fracture of the medial and lateral malleolus, Weber classification B. Upon admission, he presented with an analog pain scale (VAS) pain 10/10 with inability to walk due to pain in the left ankle region in bilateral malleoli associated with perimaleolar edema and functional limitation, inability to plantarflexion and dorsiflexion of the foot due to pain, and purulent secretion.

Study performed at Pontificia Universidad Javeriana, Bogota, Colombia.

Correspondence: Paula Andrea Solano Dazzarola. Carrera 1 #64-61, Bogota Colombia. **E-mail:** psolanodazzarola18@gmail.com. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** October 9, 2025. **Date accepted:** January 13, 2026.

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Management included open reduction and internal fixation of the tibia and left distal fibula, and repair of the deltoid ligament, performed on 01/10/2023 (Figure 1). This showed partial improvement in pain and secondary stability of the fracture focus.

The patient presented for postoperative follow-up with clinical suspicion of infected talar malunion (pain, local warmth, erythema, edema). Therefore, irrigation and debridement of the left ankle and removal of the osteosynthesis material placed on 02/28/2023 were indicated due to malunion of presumed infectious origin (Figure 2).

Subsequently, definitive treatment of the infected talar malunion was attempted; however, based on intraoperative findings, partial talectomy was performed due to varus collapse, infection, and necrosis of the talar body and neck. An antibiotic-impregnated cement spacer was temporarily placed.

Definitive management was performed with a fresh tibiotalar allograft, with evidence of infection control and concomitant ankle ligament reconstruction. Intraoperatively, a substantial defect was identified in the anterior, medial, and distal tibia; therefore, despite ligament reconstruction, the patient was left with residual varus ankle alignment (Figure 3). The patient was able to ambulate despite these findings.

During outpatient follow-up, the patient reported significant ankle pain associated with ankle osteoarthritis and varus ankle alignment. Therefore, ankle arthrodesis was performed, with intraoperative confirmation that the subtalar joint was healthy, well aligned, and stable. He currently demonstrates a solid fusion, without residual ankle malalignment, and a painless, stable subtalar joint without osteoarthritis (Figure 4).

Discussion

Talus fractures, although uncommon, are associated with high morbidity and a substantial risk of functional impairment. The talar blood supply relies on a complex anastomotic network derived mainly from branches of the posterior and anterior tibial and peroneal arteries. Disruption of this vascular inflow—particularly in displaced or dislocated fracture patterns—may result in avascular necrosis (AVN), with incidence increasing in proportion to fracture displacement as described by the Hawkins classification[2].

The Hawkins sign remains a useful radiographic marker during follow-up to infer talar viability: subchondral resorption is consistent with revascularization, whereas its absence is associated with a higher risk of AVN. When the sign is absent, magnetic resonance imaging is valuable for assessing talar perfusion and guiding timely management decisions[2].

Malunion may occur after inadequate reduction, comminution, or ineffective management of open injuries. Varus deformity is the most common pattern and is associated with altered joint mechanics, soft-tissue contracture, and early development of tibiotalar and subtalar osteoarthritis[2]. Reconstructive strategies should prioritize the restoration of limb length, axial alignment, and joint congruence[2,5,6].

Figura 1. Postoperative radiographs of open reduction and internal fixation of the left tibia and distal fibula.

Fresh total tibiotalar allograft has emerged as a therapeutic option for extensive talar bone loss[3]. A key advantage is the ability to replace the affected segment while preserving hindfoot alignment and height, potentially avoiding the marked shortening and rigidity that may accompany isolated arthrodesis. Fresh allografts may better preserve biomechanical and structural properties, thereby supporting incorporation and osseointegration[3].

In the present case, the allograft facilitated infection control, anatomic restoration, and limb preservation. Nevertheless, progression to post-traumatic osteoarthritis ultimately required tibiotalar arthrodesis, which remains the reference standard for pain relief and stabilization in advanced degenerative disease. Fixation with a locking anatomic plate provides rigid stability, promotes uniform load sharing, and has been associated with nonunion rates below 10%[4].

Figure 2. Radiograph after removal of osteosynthesis material in the ankle with subsequent varus collapse of the left ankle.

Figure 3. Fresh tibiotalar allograft of the left ankle.

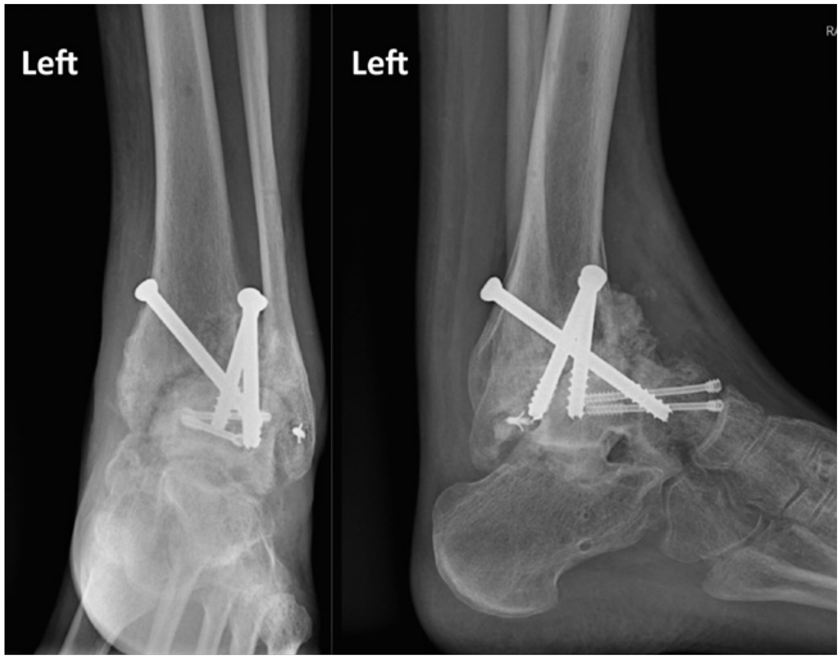

Figure 4. Radiograph after tibiotalar arthrodesis with fresh tibiotalar allograft of the left ankle.

The anterior approach used in this case provides adequate exposure of the talus and ankle joint, enabling correction of alignment and achievement of interfragmentary compression. Recent studies suggest that locking anatomic plates can improve construct stability and may reduce complications in patients with osteopenic bone or relevant metabolic comorbidities[7,8].

Successful outcomes depend on appropriate patient selection, complete eradication of infection, sufficient mechanical stability, and structured rehabilitation. Factors associated with impaired fusion include smoking, diabetes mellitus, obesity, and prolonged corticosteroid use[9]. Optimization of metabolic status and smoking cessation before reconstructive procedures is therefore recommended[9,10].

Functional prognosis after complex talar reconstruction is variable. Although ankle motion is typically reduced, preservation of limb length and stability may allow near-normal gait and improved quality of life[8,11]. Long-term clinical and radiographic follow-up is essential to identify late complications, including graft resorption and secondary osteoarthritis[8,12].

This case highlights the importance of multidisciplinary management for complex talar fractures, in which surgical decision-making must balance eradication of infection with anatomic restoration and functional preservation. Fresh allograft reconstruction is a valuable option in the reconstructive armamentarium, particularly in younger patients, in whom limb salvage and restoration of ambulation are prioritized[5,10].

Conclusions

Talus fractures remain a therapeutic challenge because of their high complication rates, with avascular necrosis and malunion being among the most frequent and functionally consequential. Optimal management requires a detailed understanding of hindfoot anatomy, vascular supply, and biomechanics. In the setting of infection with associated bone loss, a fresh total tibiotalar allograft can serve as an effective option for structural reconstruction.

This case demonstrates that infection control, anatomic restoration, and limb preservation can be achieved using advanced reconstructive techniques. When post-traumatic degeneration or residual deformity persists, tibiotalar arthrodesis remains a reliable adjunct to restore stability and relieve pain. Appropriate patient selection, meticulous surgical planning, confirmation of infection eradication, and structured rehabilitation are key determinants of success.

In young, active patients, limb-salvage strategies such as fresh total tibiotalar allografts may maintain limb length and help avoid amputation, offering a feasible alternative in complex scenarios involving infection and extensive talar bone loss. Although technically demanding, this approach is a valid option in the comprehensive management of complex talar fractures.

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Case Report

Hallux rigidus secondary to pigmented villonodular synovitis of the metatarso-phalangeal joint of the hallux: case report

Eli Ávila Souza Júnior[1], Tiago Soares Baumfeld[2]

1. Faculdade de Medicina, Universidade Federal de Alfenas, Alfenas, MG, Brazil.
2. Faculdade de Medicina da UFMG, Belo Horizonte, MG, Brazil.

Abstract

Pigmented villonodular synovitis (PVNS) is a rare, benign proliferative synovial disease that can affect the hallux metatarsophalangeal joint and manifest as secondary hallux rigidus. Clinical suspicion sometimes occurs only intraoperatively, when a synovium with blackened foci of hemosiderin deposits is found. We present a rare case of PVNS in the hallux metatarsophalangeal joint, treated surgically with synovectomy and cheilectomy.

Level of Evidence V; Diagnostic Studies; Expert Opinion

Keywords: Synovitis, pigmented vilonodular; Hallux rigidus; Metatarsophalangeal joint; Synovectomy

Introduction

The etiology of hallux rigidus is multifactorial. It can result from primary causes related to idiopathic cartilage degeneration or secondary causes, such as trauma, infection, biomechanical deformities, rheumatoid arthritis, and gout [1].

Among the rare causes of hallux rigidus is pigmented villonodular synovitis (PVNS). It is a benign proliferative synovial disease with local destructive potential, more common in large joints such as the knee, but it can also occur in the foot and ankle, including the hallux[2]. Recognition of this etiology is essential because, although less common, it can present with the diffuse form, affecting other joints, as well as malignant transformation[3].

Initial treatment of hallux rigidus is conservative; however, in cases refractory to clinical therapies, such as orthoses, infiltrations, and anti-inflammatory agents, surgical procedures may be indicated. Cheilectomy, with or without synovectomy, is widely indicated in the early stages to decompress the joint and increase range of motion[4].

The report in question shows a rare case of hallux rigidus secondary to PVNS surgically treated with synovectomy and cheilectomy.

Pigmented villonodular synovitis, also called tenosynovial giant cell tumor (TGCT), is a benign proliferative synovial disease of clonal neoplastic origin, not merely inflammatory. Genetic studies demonstrate that most cases have t (1;2)(p13; q37) chromosomal translocation, resulting in *CSF1* gene overexpression in a small subgroup of neoplastic cells. This overexpression recruits macrophages and non-neoplastic inflammatory cells, which together constitute most of the tumor volume. Histologically, TGCT is classified into two main forms: localized, also called giant cell tumor of tendon sheath (GCTTS), and diffuse**,** corresponding to the classic form of PVNS, which involves extensive synovial areas and can infiltrate adjacent tissues[5].

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

Correspondence: Eli Ávila Souza Júnior. Alameda Libânio, 72, Jardim da Colina, Alfenas, MG, Brazil. **E-mail:** elijr42@yahoo.com.br. **Conflicts of interest**: none. **Source of funding:** none. **Date received:** October 29, 2025. **Date accepted:** January 13, 2026.

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Case Report

This is a 58-year-old male patient, a bank clerk, hypertensive, who in January 2025 started experiencing pain and discomfort in the left hallux. On the visual analog scale of pain, the patient rated it 7 out of 10. There was no history of previous trauma or incidents. According to him, pain intensified when walking, when standing upright, and also when manual pressure was applied to the back of the hallux. He noted a discrete nodule in the dorsal aspect of the hallux, which often manifested as phlogosis at the site. The patient received clinical treatment from other specialists during this period, including physiotherapeutic measures, immobilization, non-hormonal anti-inflammatory drugs, and corticosteroid infiltrations, without improvement.

On clinical examination, without deformities in the loaded feet, there was an antalgic gait pattern. On inspection, edema was observed in the topography of the dorsal region of the hallux metatarsophalangeal joint. On palpation, there was a hardened dorsal nodulation of the metatarsal head, in addition to pain in the medial, dorsal, and lateral articular aspects. Regarding mobility, there was a 10-degree restriction in maximum hallux extension compared with the right side, with pain accentuation on forced extension. Normal neurovascular examination.

The patient underwent magnetic resonance imaging, which demonstrated synovitis of the hallux metatarsophalangeal joint, as well as a dorsal osteophyte of the metatarsal head and proximal phalanx (Figure 1).

Given the diagnosis of mild left hallux rigidus refractory to conservative treatment, surgical treatment with synovectomy and cheilectomy was proposed.

In August 2025, the patient underwent surgical treatment of the hallux rigidus. Intraoperatively, when performing the longitudinal capsulotomy of the hallux metatarsophalangeal joint, synovitis of unusual appearance was evidenced, with foci of blackened pigmentations, analogous to hemosiderin visible in villonodular synovitis (Figure 2). As planned, cheilectomy and extensive synovectomy were performed, sending the synovial material for anatomopathological examination (Figure 3). In the postoperative period, barouk sandals were used, with the protective support released immediately.

At one week postoperatively, the patient reported improved pain symptoms and satisfaction with the reduction in hypersensitivity. Three weeks later, the patient presented the anatomopathological result, which, on macroscopy, described four irregular fragments of soft consistency and brown color, the largest measuring 1.0 x 0.5 cm and the smallest 0.3 x 0.2 cm. On microscopy, fragments of synovial membrane form villous projections and irregular glandular invaginations, composed of two to three layers of eosinophilic cytoplasm cells and vesicular nuclei, without nuclear atypia or mitotic figures, typical of PVNS (Figure 4). Over two months of follow-up, the patient showed significant improvement in symptoms, with no significant pain or functional complaints, reporting a score of 1/10 on the visual analog scale for pain.

Discussion

Pain in the hallux metatarsophalangeal joint is a frequent complaint in adults and may result from conditions such as

Figure 1. T2-weighted coronal and sagittal cuts from magnetic resonance imaging showing signs of early hallux rigidus.

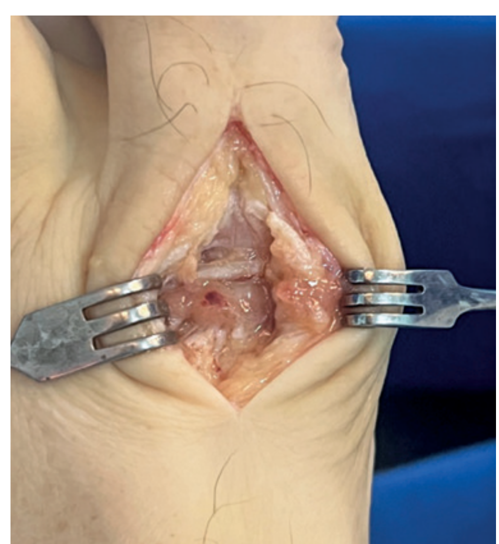

Figure 2. Intraoperative image showing synovitis with blackened hot spots.

primary hallux rigidus, hallux valgus, sesamoiditis, gouty arthritis, rheumatoid arthritis, osteonecrosis, stress fractures, or proliferative synovitis. The clinical similarity between proliferative synovitis makes etiological diagnosis difficult, especially when PVNS presents a localized lesion, with a mild synovial mass and nonspecific imaging findings[6]

Figure 3. Collected synovial material sent for pathological examination.

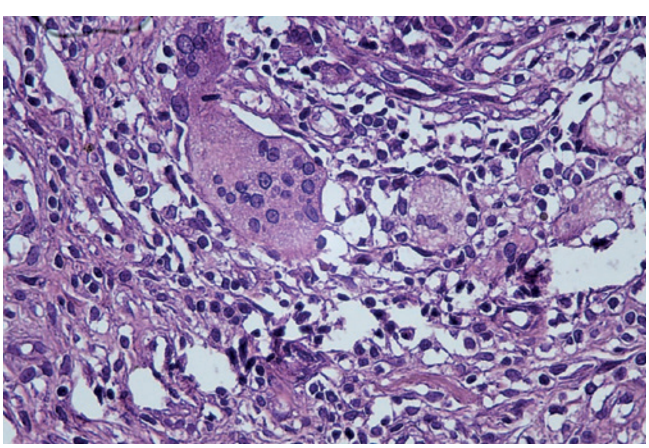

Figure 4. Histological aspect of pigmented villonodular synovitis of the hallux metatarsophalangeal joint.

Secondary hallux rigidus represents a diagnostic challenge. The literature highlights the need for advanced imaging, especially magnetic resonance imaging, but it does not always enable the identification of atypical synovitis, pigmented lesions, and bone erosions compatible with PVNS[7]. In the report in question, magnetic resonance imaging did not demonstrate any typical alterations of PVNS; however, blackened synovitis was observed intraoperatively, raising suspicion of PVNS, which was confirmed histologically.

Localized PVNS occurs most often in small joints of the hands and feet, whereas the diffuse form is more common in large joints such as the knee and ankle. Both variants share the same molecular profile but differ in synovial extension and recurrence rate, which can exceed 40% in diffuse forms[5].

Surgical treatment of hallux rigidus secondary to PVNS aims to restore joint movement and relieve pain. In mild and moderate stages, cheilectomy associated with synovectomy brings good results[4], as in this case, where pain relief and functional improvement were achieved while preserving the joint. These results are consistent with the findings of Siegel et al. [5], who, in a systematic review of PVNS of the foot and ankle, demonstrated that lower recurrence rates are achieved after complete resection.

Nabeshima et al. [8] it is the only study in the literature that describes diffuse PVNS of the hallux metatarsophalangeal joint, corroborating the rarity of this location. As shown in this report, surgical treatment resulted in significant pain reduction and functional preservation, supporting the validity of a conservative surgical approach to the joint when degeneration is not advanced.

Scheele et al. [9] reported recurrence in 34 cases of PVNS of the foot and ankle: 26.7% in localized forms and 50% in diffuse forms, underscoring the importance of confirmatory pathological examination and the need for prolonged follow-up. In the present case, the histopathological examination revealed a thickened synovial membrane with villous projections and irregular invaginations, composed of mononuclear cells with eosinophilic cytoplasm and vesicular nuclei, without atypia or mitotic figures—findings consistent with localized PVNS. Hemosiderin deposits and multinucleated giant cells were observed. These findings are consistent with those reported by Nabeshima et al.[8] and Guo et al.[6], which showed similar patterns in ankle and foot injuries. In contrast, Chen et al.[10] and Staals et al.[11] reported aggressive or malignant forms, present nuclear atypia, marked mitotic activity, and tumor necrosis, changes not found in our case, confirming the benign behavior of the lesion.

Pigmented villonodular synovitis, although rare, should be considered as an etiological possibility in hallux rigidus. The suspicion sometimes occurs only intraoperatively, considering the characteristic blackish synovium. Despite the usually benign behavior, clinical follow-up is recommended due to the risk, albeit small, of recurrence and eventual malignancy.

Authors' contributions: Each author contributed individually and significantly to the development of this article: EV *(https://orcid.org/0000-0002-5054-874X) Conceived and planned the activity that led to the study and wrote the article; TS *(https://orcid.org/0000-0001-9244-5194) Wrote the article and participated in the review process. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Case Report

Os supranaviculare contributing to anterior ankle impingement: a case report

Bruno Jorge de Sousa Cancela[1], José Inácio Menezes[1], Inês Genrinho[1], Sofia Meixedo[1], Yuriy Mazin[1], José Luís Carvalho[1]

1. Centro de Reabilitação do Norte, Porto, Portugal.

Abstract

The os supranaviculare is a rare accessory ossicle of the midfoot, typically considered asymptomatic. We report a case of chronic dorsal midfoot and anterior ankle pain in which the os supranaviculare likely contributed to an anterior ankle impingement mechanism with associated tibiotalar synovitis and extensor hallucis longus tenosynovitis. Dynamic ultrasound was essential in demonstrating mechanical interaction during dorsiflexion and in guiding targeted treatment. This case suggests that the os supranaviculare may play a clinically relevant role within the spectrum of anterior ankle impingement and should be considered in the differential diagnosis of chronic dorsal midfoot pain.

Level of Evidence IV; Case report.

Keywords: Tenosynovitis; Bone diseases; Fractures, Stress.

Introduction

The os supraviculare, also known as Pirie's bone, is one of the many reported midfoot anatomical variants[1]. It presents with an estimated 1%-3,5%[2] and typically does not cause any symptoms[1], although it is reported that, in rare instances, it can cause midfoot pain and be associated with stress fractures[3-5].

Despite these reports, the biomechanical mechanisms by which the os supranaviculare may contribute to pain remain incompletely understood, particularly regarding its interactions with adjacent soft tissues and the anterior ankle joint during motion. We present a case of chronic dorsal midfoot and ankle pain in which dynamic ultrasound evaluation supported a multifactorial mechanism involving anterior ankle impingement, tibiotalar synovitis, and extensor hallucis longus (EHL) tenosynovitis, with the os supranaviculare acting as a contributing anatomical factor.

Case description

A 59-year-old man presented with dorsal foot pain located to the anterior aspect of the tibiotarsal joint (TTJ) and midfoot. The pain had been progressively worsening for 2 years, with a mechanical pattern and exacerbation during maximal dorsiflexion. At the time of observation, the patient rated the pain at 4/10 on the Visual Numerical Scale (VNS). The patient denied any history of falls, trauma, strains, excessive exercise, or work or safety boots. Objectively, palpation of the superior aspect of the TTJ and navicular was painful, with no inflammatory signs.

Point-of-care ultrasound (US) was performed using a high-frequency linear probe with the patient in the prone position, with the knee flexed, the ankle in plantar flexion, and the foot resting on the examination table, thereby allowing optimal visualization of the TTJ and dorsal midfoot structures. This revealed TTJ effusion, lateral mediotarsal synovial effusion, and a small quantity of liquid in the EHL tendon sheath. The patient underwent a US-guided TTJ corticosteroid infiltration, with no improvement after two months, then a US-guided hyaluronic acid infiltration was performed. A year later, pain was controlled (VNS 1/10), with occasional episodes of discomfort. The patient was submitted to yearly TTJ hyaluronic acid infiltrations for the next three years, reporting to be asymptomatic for 6-8 months following each infiltration, with recurrence of pain after that period.

Study performed at the Centro de Reabilitação do Norte, Porto, Portugal.

Correspondence: Bruno Jorge de Sousa Cancela. Complete Address and Zip Code: Rua Sophia Mello Breyner 52 3.5 4430-692 Vila Nova de Gaia. **E-mail:** bruno.sousa.cancela@gmail.com. **Conflicts of interest:** None. **Source of funding:** None. **Date received:** October 17, 2025. **Date accepted:** January 20, 2026.

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Five years after the initial presentation of symptoms, the case was reviewed. The radiological studies initially performed (ankle and foot radiography and magnetic resonance imaging (MRI) shown in Figures 1-3) demonstrated no TTJ degeneration, a dorsal osteophyte on the talar neck, and an os supranaviculare, suggesting a potential site of mechanical conflict with surrounding structures. An ultrasound scan was repeated, demonstrating accumulation of fluid in the EHL tendon sheath, with thickening of the synovial sheath (primarily adjacent to the os supranaviculare) and dynamic friction between these structures. Dynamic maneuvers, including active and passive ankle dorsiflexion and hallux flexion–extension, were performed, demonstrating mechanical interaction between the EHLtendon sheath and the os supranaviculare.

The patient underwent US-guided infiltration of the EHL tendon sheath adjacent to the os supranaviculare with 40 mg of methylprednisolone. Fifteen months after the procedure, the patient reported an 80% subjective improvement and no need for further procedures. A ten-month follow-up MRI (Figures 4-6) confirmed an os supranaviculare and showed no signs of EHL tenosynovitis.

Discussion

Most accessory ossicles of the foot are infrequent or rare, including the os supranaviculare[2]. This ossicle can be mistaken for an avulsion fracture of the talonavicular joint[1], but the patient denied any history of significant trauma or acute onset of pain and swelling in the region, making this hypothesis very unlikely.

Figure 1. Ankle and foot radiograph (side view) showing accessory ossicle (os supranaviculare) and absence of degenerative changes of the tibiotarsal joint.

Figure 2. Initial presentation magnetic resonance imaging (density proton sagittal view) showing os supranaviculare and absence of degenerative changes of the tibiotarsal joint.

Figure 3. Initial presentation magnetic resonance imaging RI (T2 transverse view) showing subtle thickening of the extensor hallucis longus tendon.

Considering the symptoms and the initial US findings (mainly the TTJ effusion), the most likely hypothesis was ankle osteoarthritis, which is relatively common, and it could partially explain the pain[6]. The good response to hyaluronic acid can also point to this diagnosis, but the absence of radiographic findings of degeneration of the TTJ point to early-stage osteoarthritis (if present). Importantly, the recurrent pattern of symptoms despite repeated intra-articular interventions raised the possibility of a concomitant extra-articular pain generator.

The hypothesis of midtarsal or tarsometatarsal osteoarthritis was also considered, based on US findings of synovial effusion in the region and MRI evidence of bone oedema; however, these findings were inconsistent with the clinical history and physical examination, making this diagnosis less likely.

Given the location of the pain, pathologies of the navicular bone should also be considered and excluded. In particular, Müller–Weiss syndrome, which represents an osteonecrosis-like process of the navicular bone, typically presents with midfoot pain, often associated with deformity and collapse of the longitudinal arch[7]. In this patient, there was no history of trauma, no physical exam findings compatible with this diagnosis, and the imaging studies showed no navicular abnormalities. Another important differential diagnosis is a navicular stress fracture, an overuse injury generally seen in the context of repetitive loading of the foot, such as in

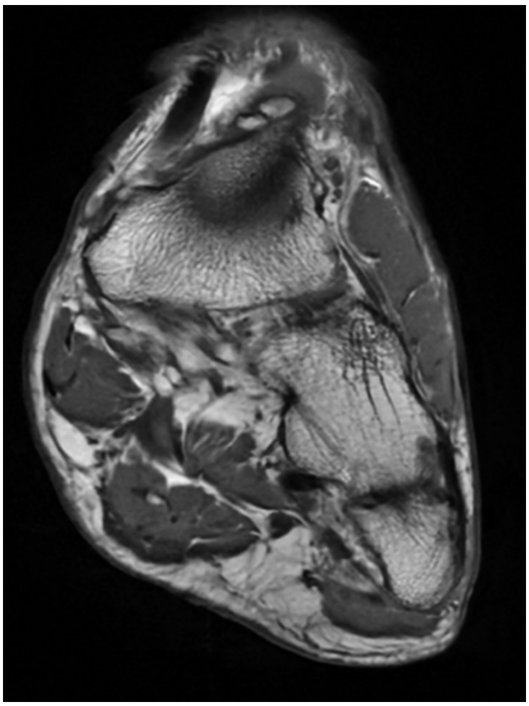

Figure 4. Five-year follow-up magnetic resonance imaging (T1 coronal view) showing os supranaviculare.

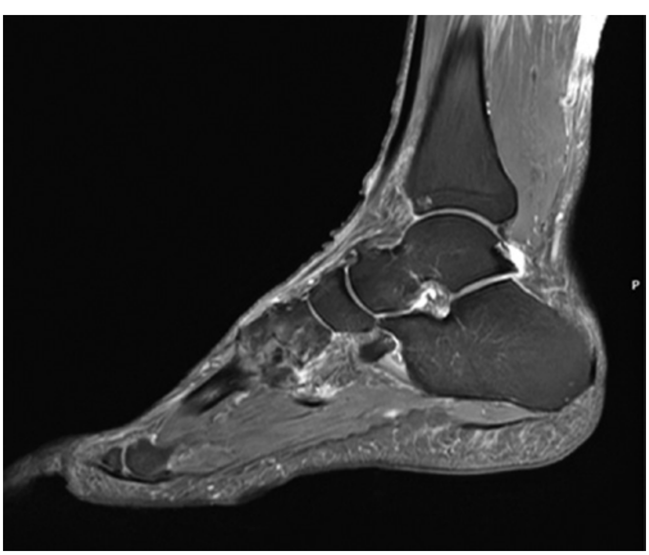

Figure 5. Five-year follow-up magnetic resonance imaging (density proton sagittal view) showing os supranaviculare and bone oedema of the tarsometatarsal joint.

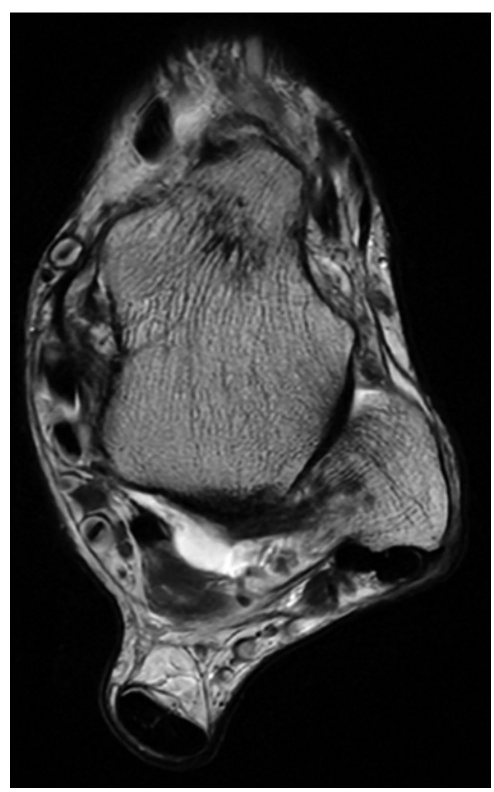

Figure 6. Five-year follow-up magnetic resonance imaging (T2 transverse view) showing no thickening or fluid accumulation of the extensor hallucis longus tendon.

athletes, which manifests with pain exacerbated by weight-bearing and localized tenderness over the navicular bone[8]. However, in this patient, both the epidemiological context (occupational and sports history) and the MRI findings (absence of navicular bone oedema) make this hypothesis unlikely.

The symptoms and anatomical region also raise the possibility of compression beneath the inferior extensor retinaculum (anterior tarsal tunnel syndrome). However, the absence of radiating pain typical of the deep peroneal nerve distribution (between first and second toes), absence of neuropathic complaints (paresthesia, burning pain) or motor deficits, together with imaging findings that localized inflammation to the EHL tendon sheath rather than to neural structures, made retinacular entrapment less likely in this case.

After reassessment and repeat US scan, the findings were consistent with EHL tenosynovitis, with sheath thickening and fluid accumulation most evident adjacent to the os supranaviculare. In addition, radiographic review revealed a dorsal prominence of the talar neck, consistent with a dorsal osteophyte, which may contribute to anterior impingement. Taken together, these findings support a broader hypothesis in which the os supranaviculare participates in an anterior ankle impingement complex, potentially promoting repetitive conflict during dorsiflexion, intra-articular synovitis, and secondary irritation of adjacent soft tissues, including the EHL tendon sheath.

We opted to treat the patient with a corticosteroid infiltration into the EHL tendon sheath due to the US finding of fluid accumulation in the region in contact with the os supranaviculare (without any structural involvement of the tendon), making the procedure safe. We expected this treatment to reduce fluid accumulation by controlling the inflammatory process and, secondarily, by potentially decreasing local mechanical irritation. The patient's sustained improvement supports the presence of an inflammatory component at this site. Nevertheless, the patient's prior response to intra-articular procedures suggests that intra-articular synovitis and/or early osteoarthritis may have also contributed to symptoms. Therefore, clinical evolution supports a multifactorial mechanism, namely anterior impingement-related conflict with TTJ synovitis and EHL tenosynovitis, where the os supranaviculare likely plays an important role in this patient.

Based on the findings and proposed pathophysiology, we can argue that the corticosteroid infiltration can be repeated in the future if symptoms reoccur. Surgical intervention can also be considered if symptoms are persistent or refractory, removing the accessory ossicle and eliminating this likely contributing factor of the tenosynovitis.

To our knowledge, this is the first report using dynamic US to support a soft tissue mechanism (anterior impingement with secondary TTJ synovitis and EHL tenosynovitis) to explain a symptomatic os supranaviculare, whereas prior reports have primarily emphasized its association with navicular stress injury in athletic populations[9,10].

The os supranaviculare is a rare anatomical variant that is usually asymptomatic; however, it may contribute to dorsal midfoot and ankle pain as part of a broader spectrum of anterior ankle impingement. This case illustrates that the ossicle can participate in a multifactorial mechanism involving anterior impingement-related conflict. Dynamic ultrasound proved particularly valuable in identifying soft-tissue involvement and mechanical interaction during motion, supporting both diagnostic clarification and targeted treatment. The os supranaviculare should therefore be considered in the differential diagnosis of chronic dorsal midfoot or anterior ankle pain when more common causes have been excluded.

Authors' contributions: Each author contributed individually and significantly to the development of this article: BJSC *(https://orcid.org/0000-0003-1461-5340) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, involved in the bibliographic review and formatting of the article; JIM *, SM *(https://orcid.org/0009-0007-0334-3905), and YM *Participated in the review process and contributed to the bibliographical review; IG *(https://orcid.org/0000-0003-1159-0491) Conceived and planned the activities that led to the study, participated in the review process and contributed to the bibliographical review; JLC * Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, conducted clinical examination of the patient. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Case Report

Cholesterol granuloma presenting as a large calcaneal cyst: A case report

Athanasios Bampalis[1,2], Spyridon Kaliarntas[2], Zannis Almpanis[1], Maria Rempelou[3], Emmanouil Charitakis[4], Odysseas Paxinos[1,5]

1. Department of Pathology at the 251 Hellenic Air Force General Hospital, Athens, Greece.
2. Hygeia Hospital, Athens, Greece.
3. Lefkos Stavros- The Athens Clinic, Athens, Greece.
4. Department of Plastic Surgery - Microsurgery, Burns Center, and Melanoma Reference Center of general Hospital of Athens "G. Gennimatas", Athens, Greece.
5. Department of Orthopedic and Traumatology Henry Dunant Hospital Center, Athens, Greece.

Abstract

Cholesterol granuloma (CG) is a rare chronic inflammatory lesion that typically affects the temporal bone. Involvement of the appendicular skeleton is extremely rare, with only a limited number of cases described in the literature. We report a unique case of CG occurring in the calcaneus. We present a 23-year-old female amateur athlete with a 6-month history of pain and swelling of the left calcaneus following physical activity. Imaging indicated a large calcaneal cyst, and the patient underwent curettage and bone grafting. The histopathological examination revealed CG, making this the first reported case involving the calcaneus. This case highlights the need to include this rare disease in the differential diagnosis of cystic bone lesions.

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

Keywords: Calcaneus; Cysts; Rare diseases; Granuloma.

Introduction

Calcaneal bone cysts are usually identified as incidental radiologic findings and rarely require surgical intervention[1]. Cholesterol granulomas (CG), although known as usual lesions of the petrous part of the temporal bone, have also been reported in the femur, the radius, and the humerus[2,3]. We report a unique case of CG in the calcaneus along with a review of this rare pathology.

Case description

A 23-year-old female amateur athlete presented with a 6-month history of pain and discomfort in her left calcaneus during sports activities. A lateral radiograph of the calcaneus revealed a well-defined cystic lesion within the calcaneal body, with benign radiographic features and a size greater than that typically seen in simple bone cysts (Figure 1). Computed tomography (CT) imaging revealed a large fluid-filled cystic lesion (46 × 29 × 22 mm) with sclerotic yet thin cortical margins (Figure 2). Magnetic resonance imaging (MRI) with gadolinium contrast demonstrated minimal peripheral enhancement and absence of fatty tissue, findings consistent with a benign lesion (Figure 3). To prevent a pathological fracture of the calcaneus, the patient was scheduled for surgery with a provisional diagnosis of an atypical aneurysmal bone cyst based on lesion size and expansile morphology. A standard lateral approach to the calcaneus was performed, and a cortical window of 20 × 20 mm was elevated and attached to the soft tissue flap (Figure 4). Following evacuation of chocolate-brown fluid from the cyst, a yellow-grey soft-tissue mass measuring 20 × 10 mm was identified, loosely attached to the cavity wall, and was sent for microbiological culture and histopathological examination. The cyst cavity was initially treated with

Study performed at the 251 Hellenic Air Force General Hospital, Athens, Greece.

Correspondence: Odysseas Paxinos. Avenue Mesogeion 131, 11526, Athens, Greece. **E-mail:** odypax@yahoo.com. **Conflicts of interest:** none. **Source of funding:** none. **Date received:** September 24, 2025. **Date accepted:** January 30, 2026.

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curettage and alcohol application and then filled with a mixture of packed autologous iliac crest bone and allograft bone. The cortical window was repositioned by suturing the full-thickness skin flap. Histopathological analysis identified the lesion as a CG (Figure 5). The patient's postoperative recovery was unremarkable, and she ambulated non-weight-bearing in a cast for six weeks, after which she progressed to a walking boot for another six weeks. At 12 weeks, the grafted area had healed sufficiently, both radiologically and clinically, to allow activities of daily living and initiation of physiotherapy for subtalar motion. A full return to sports was possible at six months, accompanied by notable radiological improvement (Figures 6 and 7). The study was approved by the Ethics and Research Commission of the Institution, and informed consent was obtained from the patient for publication of this case report and accompanying images.

Figure 1. Lateral radiograph of the calcaneus demonstrating a well-defined cystic lesion within the body of the calcaneus.

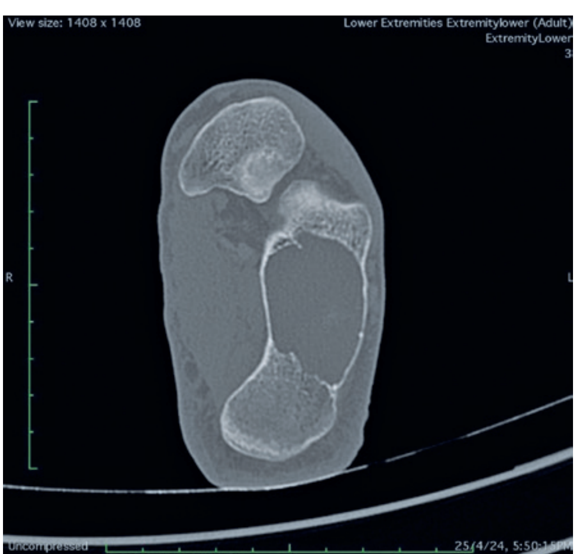

Figure 2. A computed tomography scan revealing a large fluid-filled cystic lesion (46x29x22mm) with a sclerotic but thin cortical margin.

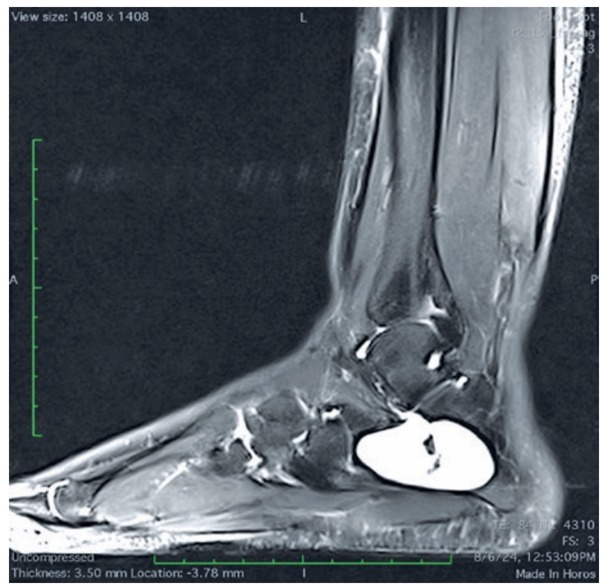

Figure 3. A magnetic resonance imaging with gadolinium contrast showing minimal marginal uptake and no fat tissue.

Figure 4. Image taken during the surgery that depicts the cavity after the cyst curettage and alcohol irrigation.

Discussion

Cholesterol granulomas are benign, expansile cystic lesions characterized by chocolate-brown fluid content and a surrounding granulation tissue reaction to cholesterol crystals[3]. Initially described by Manasse in 1894, the nomenclature of these lesions has evolved to use the term "cholesterol granuloma," although alternative labels such as cholesteatoma and xanthomatosis have also been used[4]. Cholesterol granuloma is more common in males, and although predominantly associated with the mastoid process, middle ear, and the temporal bone, it has also been reported in various locations, including the central nervous system, the orbital cavity, the paranasal sinuses, the thyroid gland, the mediastinum, the ovaries, the peritoneum, and the breast[5,6]. Macroscopically, the lesion presents as yellowish-brown, soft, or sandy-textured, well-demarcated masses, in which vascular structures are frequently observed[5,6]. The hallmark histological finding is cholesterol crystals encased within fibrous granulation tissue and surrounded by foreign-body multinucleated giant cells[5,7]. Immunohistochemistry has demonstrated increased expression of angiogenic markers, such as VEGF and CD34, reflecting active vascular proliferation within these lesions[6]. There is no clear correlation between CG and elevated serum cholesterol levels[3,8]. The pathogenesis of CG remains poorly understood, with various hypotheses proposed[2,5]. The obstruction vacuum theory attributes lesion formation to negative-pressure-induced hemorrhage following impaired ventilation[3]. Alternatively, the exposed marrow theory suggests that trauma releases marrow lipids, initiating cholesterol crystal accumulation and a granulomatous immune response, which may be perpetuated by neovascularization and a self-sustaining hemorrhage-inflammation cycle[6,8]. In the present case, the patient's young age and athletic profile imply repetitive calcaneal loading and possible microtrauma, leading to intraosseous hemorrhage, subsequent cholesterol crystal deposition, and foreign body granulomatous reaction. In addition, contributions from perlecan-mediated trapping of oxidized

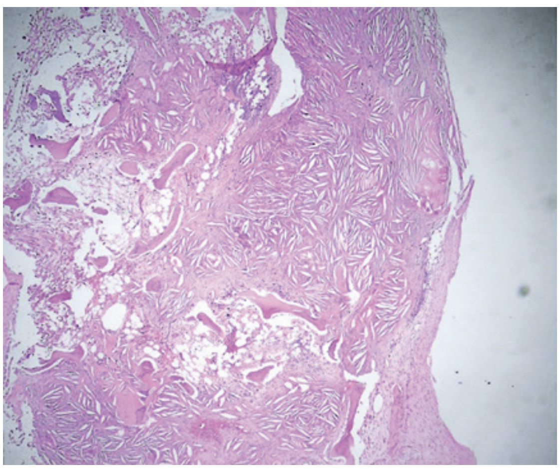

Figure 5. Histological image stained with hematoxylin and eosin showing numerous needle-shaped cholesterol clefts surrounded by inflammatory cells and bone pieces.

Figure 6. Six-month postoperative lateral radiograph demonstrating significant radiological improvement.

Figure 7. Six-month postoperative anteroposterior radiograph demonstrating significant radiological improvement.

low-density lipoproteins within granulation tissue may further amplify cholesterol crystal formation[4]. Due to the subtle progression and mild symptoms, differential diagnosis can be challenging[1]. Simple bone cysts typically present as centrally located, well-defined lucent lesions in younger patients, usually without cortical expansion or internal septations[1]. Aneurysmal bone cysts are more aggressive, characterized by expansile remodeling, cortical thinning, internal septations, and fluid-fluid levels on MRI[1,3]. Giant cell-rich lesions, including giant cell tumors, often demonstrate locally aggressive bone destruction and occasional soft-tissue extension[3]. Xanthomatous lesions, histologically, may resemble CGs but are commonly associated with lipid metabolism disorders and show more diffuse marrow infiltration[5]. Malignant tumors of the calcaneus are uncommon and typically present with ill-defined margins, cortical destruction, and periosteal reaction, features not characteristic of CG[1,3]. Radiographically, CG are typically described as well-demarcated lytic lesions with regular margins and minimal reactive sclerosis[1]. In the present case, lateral radiographs demonstrated a benign appearing calcaneal cyst that was notably larger than expected for a simple bone cyst. Computed tomography imaging revealed a large fluid-filled lesion with thin but sclerotic cortical margins, smooth erosion, and no aggressive features, consistent with the reported CG morphology[4]. Magnetic resonance imaging findings further supported this diagnosis, showing minimal peripheral enhancement after gadolinium administration and the absence of fatty components, consistent with the characteristic high-signal cystic nature of CG and with the limited enhancement patterns described in the literature[2,4]. Although not performed in this case, conventional angiography has been described as a useful adjunct for evaluating lesion vascularity and guiding preoperative embolization when significant intraoperative bleeding is anticipated[9]. In conclusion, the imaging profile favored CG over alternative cystic or aggressive lytic lesions. In small lesions, bone grafting has been effective, whereas in more extensive lesions, bone cement implantation and internal fixation have been used[3]. Overall, the goal of surgical management is complete excision with minimal invasiveness, along with improvement in symptoms[10]. Postoperative outcomes for CG are generally favorable, with minimal recurrence reported in the literature[2,3].

This case contributes to the limited literature on cholesterol granuloma of the calcaneus and emphasizes the importance of considering this rare benign entity in the differential diagnosis of calcaneal cystic lesions, particularly in young and active patients. Accurate recognition relies on histopathological confirmation, as imaging findings may mimic those of other benign cystic lesions. Curettage with bone grafting was an effective approach, supporting its use as a reliable management option for cholesterol granuloma.

Authors' contributions: Each author contributed individually and significantly to the development of this article: AB *(https://orcid.org/0009-0001-1279-0818) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, performed the surgeries, data collection, performed the bibliographic review, formatting of the article, survey of the medical records, and performed the clinical examination; SK *(https://orcid.org/0009-0007-2379-0745), MR *(https://orcid.org/0009-0009-7452-7861), and EC *(https://orcid.org/0009-0009-4550-2024) Interpreted the results of the study, participated in the review process, performed the bibliographic review, and formatting of the article; ZA *(https://orcid.org/0009-0006-8723-8071) Performed the surgeries, data collection, survey of the medical records, and performed the clinical examination; OP *(https://orcid.org/0000-0001-5449-7436) Conceived and planned the activities that led to the study, interpreted the results of the study, participated in the review process, performed the surgeries, data collection, survey of the medical records, and performed the clinical examination. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Technical Tips

Modified posteromedial approach for combined posterior and lateral malleolar fixation in complex ankle fractures: A technical insight apropos a single clinical case

Rodrigo Pesántez[1], Antonio Solano Noguera[1], Robinson Esteves Pires[2,3]

1. Department of Orthopaedic Surgery, Fundación Santa Fé de Bogotá, Bogotá, Colombia
2. Postgraduate Program in Clinical Radiology, Federal University of São Paulo (UNIFESP), Sao Paulo, SP, Brazil
3. Department of the Locomotor System. Federal University of Minas Gerais, Belo Horizonte, MG, Brazil

Abstract

The fixation of posterior malleolar fractures has gained increased relevance over the past decade due to its essential role in restoring ankle joint stability and function. Various approaches and fixation strategies have been described in the literature, typically requiring multiple incisions, thereby increasing the complexity and risk of soft-tissue complications. The aim of this study is to present a technical note describing a single modified posteromedial approach for combined posterior, medial, and lateral malleolar fixation in complex ankle injuries. This technical note outlines the surgical steps of a modified posteromedial approach that enables the fixation of all three malleoli through a single incision. The approach provides access to posterolateral, posteromedial, and medial distal tibial surfaces as well as the lateral malleolus. The technique is demonstrated in a single representative clinical case of a complex trimalleolar ankle fracture.

Level of evidence V; Expert Opinion.

Keywords: Ankle fractures; Fracture Fixation, Internal; Orthopedic Procedures.

Introduction

Posterior malleolar fractures are complex injuries that require precise management to restore ankle congruency, joint stability, and function[1,2]. Traditionally, several surgical approaches and fixation techniques have been developed to address these fractures, including anterior-to-posterior fixation with lag screws and buttressing plates via posterolateral and/or posteromedial approaches[1,2]. However, these methods often require multiple incisions, potentially increasing surgical complexity and the risk of soft-tissue-related complications[1,3-5].

The posteromedial approach and, more recently, the modified posteromedial approach have emerged as valuable options for treating posterior malleolar fractures, offering direct access to the fracture with the advantage of a wider exposure of the posterior surface of the distal tibia. The posteromedial approach allows for effective visualization and reduction of posterior malleolar fragments (posterolateral, posteromedial, or both), making it a helpful choice in specific clinical scenarios[4]. Furthermore, the modified posteromedial approach offers a better attack angle than the traditional posterolateral approach for reducing small intercalary depressed fragments, which are frequently associated with posterior malleolar fractures[3]. Despite its potential advantages, the modified posteromedial approach is typically underutilized for combined posterior and lateral malleolar fixation, with the posterolateral approach being more commonly employed[2].

Study performed at the Department of the Locomotor System. Federal University of Minas Gerais, Belo Horizonte, MG, Brazil.

Correspondence: Robinson Esteves Pires. Av. Alfredo Balena, 190 - Santa Efigênia, 30130-100, Belo Horizonte, MG, Brazil. **Email:** robinsonestevespires@gmail.com. **Conflicts of interest**: none. **Source of funding:** none. **Date received:** November 10, 2025. **Date accepted:** April 04, 2026.

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The posterolateral approach provides access to both the lateral malleolus and the posterolateral fragment of the posterior malleolus. However, it poses limitations in addressing posteromedial fragments due to restricted visibility. Moreover, the posterolateral approach can be associated with difficult rehabilitation for ankle dorsiflexion gain[3-7]. Consequently, there is a perspective to explore an alternative approach that can offer comprehensive fixation for both lateral and posterior malleolar fractures through a single incision

This study hypothesizes that combined lateral and posterior malleolar fixation can be effectively achieved through a single modified posteromedial approach. This technique aims to avoid the need for an isolated lateral approach and to mitigate the disadvantages of the posterolateral approach, particularly its limitations in addressing posteromedial and depressed intercalary fragments.

Methods

Informed consent and ethical approval were obtained for publication of the article.

Indications and surgical strategy

The modified posteromedial approach is indicated for pilon fractures with posterior components and for posterior malleolar fractures, including isolated posteromedial or posterolateral fragments, combined posteromedial and posterolateral fragments, and a single unique posterior malleolus extending across the entire posterior surface of the distal tibia. In this technical note, we thoroughly describe a technique to address combined lateral, posterior, and medial malleolar fractures using a single modified posteromedial approach.

Depending on the trauma energy and the soft-tissue condition, fixation can be performed in two stages, with a transarticular external fixation until the wrinkle sign appears, allowing for safe internal fixation.

Surgical technique

The patient is typically positioned prone, and a lazy-L skin incision is made 1 cm medial to the Achilles tendon insertion and extends proximally for about 15 cm along the medial border of the Achilles tendon. Distally, we continue the incision in a lazy-L fashion posterior and distal to the medial malleolus to expose the anteromedial tibia and address the medial malleolus and medial comminution. Then, we approach the superficial fascia to expose the Achilles tendon and the distal part of the soleus muscle. The Achilles tendon and its sheath are retracted laterally, and the posterior tibialis tendon is retracted medially, to expose the transverse intermuscular septum (the floor of the superficial posterior compartment) and open it longitudinally to access the deep posterior compartment. The posterior surface of the distal tibia is approached through the plane between the flexor hallucis longus (FHL) and the neurovascular bundle (NVB) (tibial nerve and posterior tibial artery). Care must be taken to protect the NVB throughout the procedure, and all efforts must be made to avoid excessive traction on the NVB and the soft tissues, especially when addressing the posterolateral fragment and the lateral malleolus using Hohmann retractors. To address the posterolateral surface of the distal tibia and the lateral malleolus, it is strongly recommended to extend the skin incision proximally by at least 10 cm. The proximal extension of the skin incision prevents excessive traction on the NVB. This proximal extension facilitates the exposure of the lateral aspect of the ankle. Short skin incisions require excessive traction on the soft tissues, increasing the risk of complications[7].

This approach enables the creation of multiple windows for fragment-specific fixation, carefully preserving soft tissues to minimize the risk of damage to the NVB. These windows, in addition to the reduction and the fixation strategies, will be described in detail below:

1. Identify the lateral border of the FHL and retract it medially to assess and reduce the posterolateral fragment and the lateral malleolus. Retracting the peroneal tendons laterally can help in exposing the fibula to fix the fractures.
2. Identify the medial border of the FHL and the NVB (protect the NVB using a vessel loop); retract the FHL laterally and the NVB medially to expose the posteromedial fragment.
3. Identify the lateral border of the flexor digitorum longus (FDL) tendon medially to the NVB to expose the medial border of the posteromedial fragment.
4. Identify the sheath and tunnel of the posterior tibialis tendon and, if necessary, open it to retract the tendon.
5. Anterior to the posteriorly opening tibialis sheath, the medial malleolus is exposed up to the anteromedial tibia. In cases of medial malleolus fractures, everting the medial malleolus can help in assessing impaction on the distal tibia medially and to assess articular reduction of the posterior malleolus.

Figure 1 illustrates three of the five possible windows for treating the posterior ankle fractures. The posterior malleolus is addressed first, reduced using a ball-spike pusher, and provisional key wires are applied, avoiding the area designated for plate placement. If impacted articular fragments of the posterior malleolus are present, the open book technique should be applied to reduce the impaction and fix the fracture.

Table 1 outlines the five potential windows for addressing posterior ankle fractures.

Fixation of the posterior malleolus is performed using isolated or combined 2.4- or 2.7 mm minifragment plates in a buttressing fashion, depending on the fracture pattern. Either straight, hook, or T-shaped plates can be utilized, depending on the specific requirements of the fixation.

Using a Hohmann retractor placed on the posterolateral surface of the lateral malleolus, the fibula can be addressed and reduced with small pointed clamps. A posterior straight

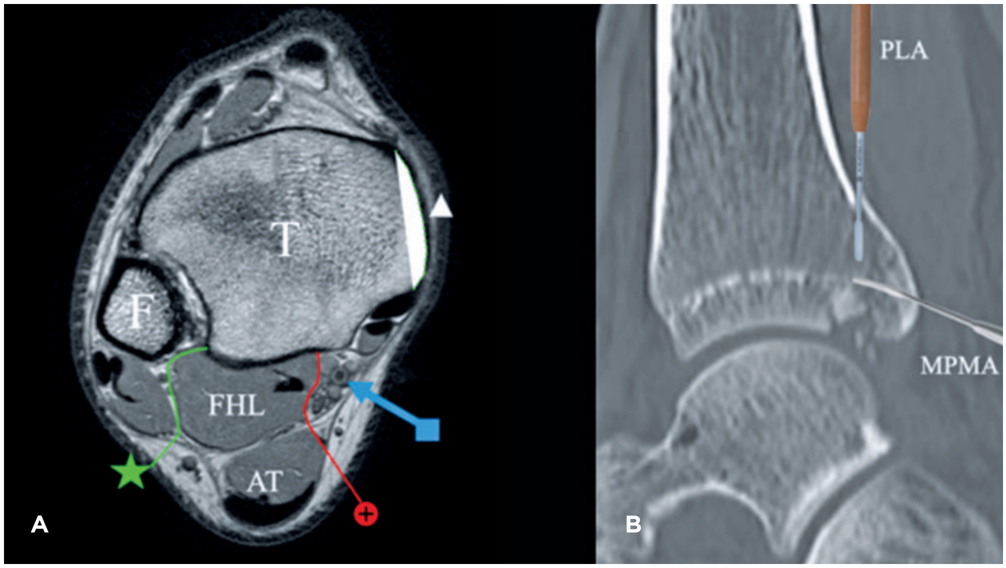

Figure 1. (A) Axial magnetic resonance imaging of the ankle illustrating the following structures: Tibia (T), Fibula (F), Achilles tendon (AT), and flexor hallucis longus (FHL). The green star and line represent the window to approach the posterolateral surface of the tibia and fibula. The red cross and line indicate the window between the FHL and the neurovascular bundle, which addresses the entire posteromedial surface of the distal tibia. The blue square and arrow identify the neurovascular bundle, while the white triangle marks the anteromedial aspect of the tibia, located anterior to the posterior tibialis tendon. (B) Note the difference in the reduction angles for the intercalary fragment between the posterolateral approach (PLA) and the modified posteromedial approach (MPMA). Observe that the reduction angle is more favorable when using the MPMA.

Table 1. Observe the anatomical windows that can be developed to address the posterior aspect of the ankle

Window	Interval	Application
1st	Peroneal tendons – FHL	Fibula/lateral malleolus Posterolateral fragment
2nd	FHL – NVB	Posterolateral fragment
3rd	NVB - FDL	Posterolateral fragment
4th	TPT subluxated medially – FDL laterally	Posterior colliculus
5th	FDL/TPT retracted laterally	Anterior colliculus Medial malleolus

FHL: Flexor hallucis longus; NVB: Tibial neurovascular bundle; TPT: Tibialis posterior tendon.

2.4 mm or 2.7 mm minifragment plate is then used to fix the fibula in a buttressing fashion. Wagstaffe fragments, anterior malleolar fractures, and equivalents (quadrimalleolar ankle fractures) can be addressed by flexing the knee and performing additional anterior approaches in an upside-down manner. If syndesmotic fixation is required, it can be performed as usual, applying either rigid or elastic constructs.

Postoperative rehabilitation protocol

The postoperative rehabilitation protocol includes early range of motion exercises. Weight-bearing is allowed with crutches and ankle protection in a boot, starting with touch-down weight-bearing and progressively increasing weight as the fracture heals. Full weight-bearing is permitted after complete fracture healing, typically around 6-8 weeks.

Case 1 illustrates the surgical technique

A 52-year-old male patient suffered a rotational injury to his left ankle following a fall down stairs. Upon admission to the emergency department, he was diagnosed with a dislocation and trimalleolar ankle fracture (AO/OTA 44B3.2). After closed reduction in the emergency department, immobilization was applied, and a computed tomography scan was performed to assess the fractures in detail. When soft tissues were amenable to open reduction internal fixation (on the sixth day), surgery was performed using a modified posteromedial approach as described by Assal et al.[3,4], extending anteriorly with the windows described by Wang et al.[5]. Figures 2 and 3 provide an overview of the preoperative imaging.

Five windows were utilized to achieve adequate reduction and fixation of the fibula, posteromedial and posterolateral aspects of the tibia, and the medial malleolus (Figures 4-6).

Figure 2. (A) Radiographs of the left ankle demonstrating the fracture dislocation. (B) Radiographs of the ankle after reduction and provisional immobilization with a cast. (C) Axial computed tomography scan illustrating the complexity of the posterior malleolar fracture. (D) Coronal computed tomography scan illustrating the trimalleolar fracture. (E) Sagittal computed tomography scan illustrating the posterior malleolar fracture.

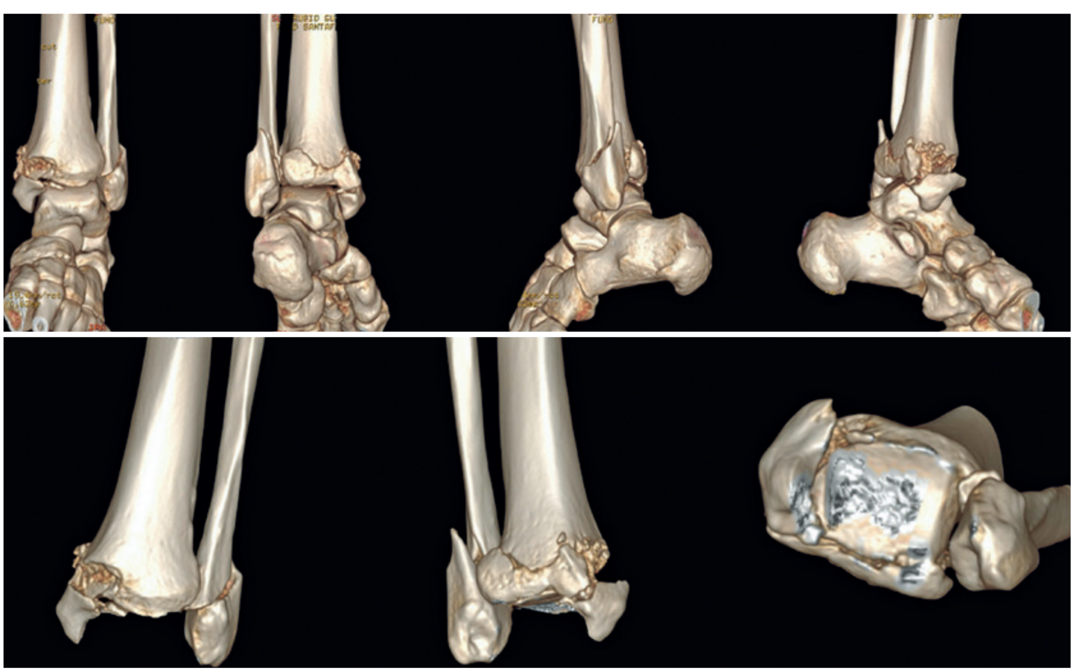

Figure 3. Three-dimensional computed tomography scan showing a trimalleolar fracture with detailed visualization of the fracture components.

Figure 6 illustrates the radiographs and the clinical aspect of the ankle after fracture healing.

Discussion

The fixation of posterior malleolar fractures has gained attention in recent years due to the crucial role these fractures play in ankle stability and function[1]. Traditional approaches, such as anterior-to-posterior fixation with lag screws and the use of posterolateral and posteromedial buttressing plates, have provided various strategies to address these complex injuries[1]. The posterolateral approach, in particular, has been widely adopted for its effectiveness in accessing both the lateral malleolus and the posterolateral fragment of the posterior malleolus[2]. However, this approach has limitations in addressing posteromedial fragments and can complicate rehabilitation due to restricted ankle dorsiflexion[3-7]. Moreover, impacted fragments of the posterior malleolus are challenging to address using posterolateral approaches due to the unfavorable angle to achieve and maintain reduction of the impacted fragment[1].

Our study focuses on the modified posteromedial approach, which has demonstrated significant advantages in treating posterior malleolar fractures. This approach allows direct visualization and effective reduction of the posterior malleolus while minimizing soft-tissue disruption. Assal et al.[3,4] have highlighted the benefits of this approach in providing a comprehensive view of the posterior tibia and facilitating the management of complex fracture patterns.

Assal et al.[4] compared exposure to the distal tibia using three approaches: posterolateral, posteromedial, and a modified posteromedial approach. The study found that the posteromedial approach provides superior exposure to the medial and central parts of the posterior malleolus, with a coverage of 83% and 61%, respectively, while the posterolateral approach offers better access to the lateral and central parts, covering 86% and 68%, respectively. However, the modified posteromedial approach combines

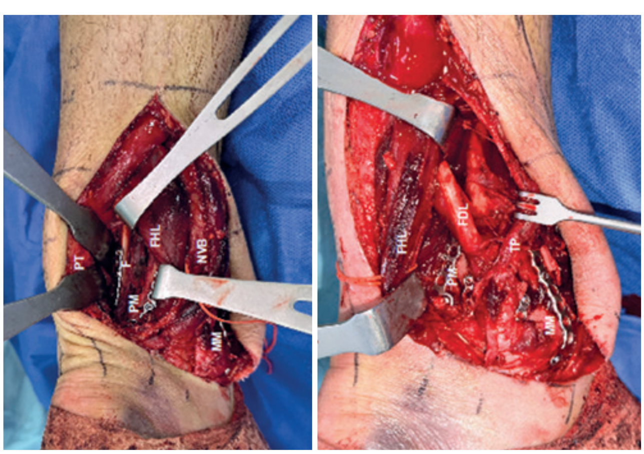

Figure 4. Intraoperative images highlighting the anatomical landmarks and the potential windows accessible through the modified posteromedial approach. **PT:** Peroneal tendons, **F:** Fibula, **PM:** Posterior malleolus, **FHL:** Flexor hallucis longus, **NVB:** Neurovascular bundle, **MM:** Medial malleolus, **FDL:** Flexor digitorum longus, **TP:** Tibialis posterior.

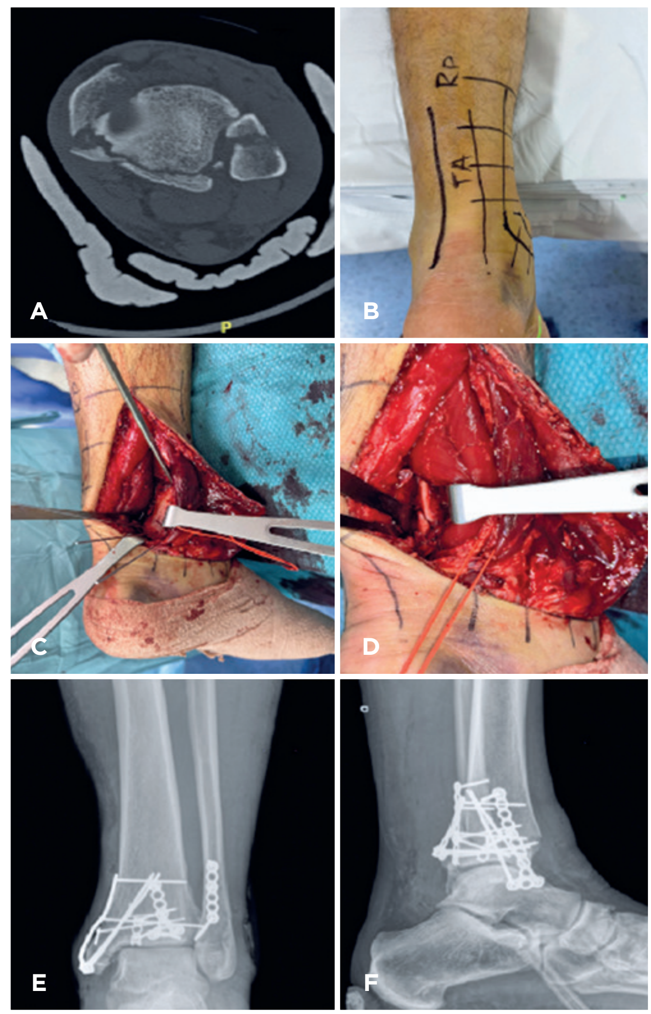

Figure 5. Technique used for the reduction and fixation of the trimalleolar fracture through the single modified posteromedial approach. (A) Axial computed tomography scan of all fracture components involving the posterior, medial, and lateral malleolus; (B) Preoperative skin marking; (C) Provisional fixation of the posteromedial fragment with K wires. Observe the interval between FHL and NVB; (D) Exposure of fibula fracture. Peroneal tendons are retracted laterally and FHL medially; (E-F) Final radiograph images. A buttress plate was applied to the lateral posterior malleolar fractures. The medial malleolus was fixated with an anti-gliding plate and two bicortical screws placed from the anteromedial to the posterolateral direction.

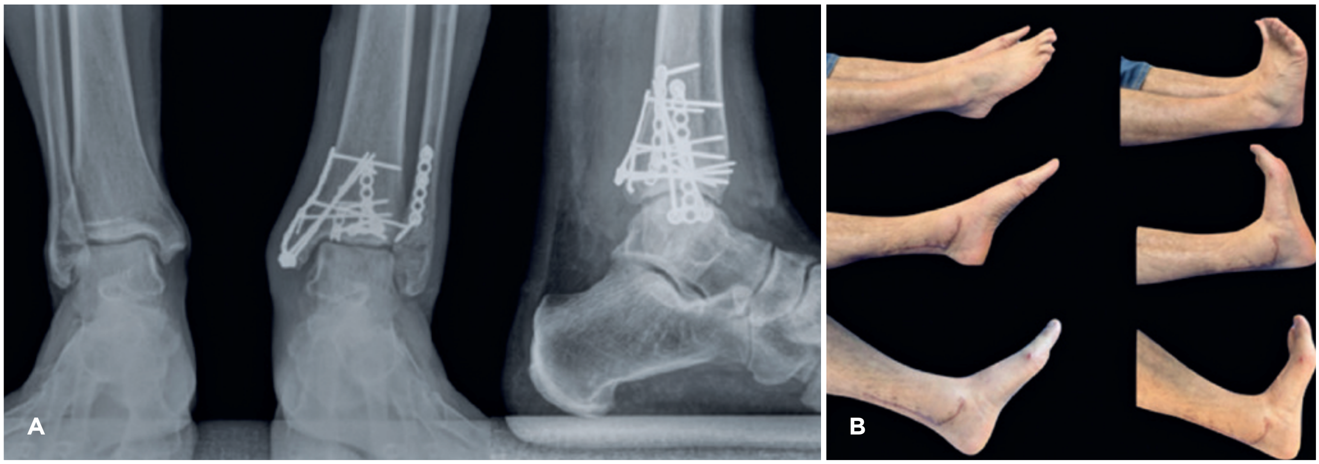

Figure 6. (A) Full-weight-bearing follow-up radiographs four months after surgery. (B) The surgical wound was completely healed at four months postoperatively, and ankle motion was clinically functional and nearly symmetrical when compared with the contralateral side.

the benefits of both, allowing for extensive visualization of the entire posterior surface of the distal tibia with an overall coverage of 92%. This comprehensive exposure is particularly advantageous for addressing combined fractures involving both posteromedial and posterolateral fragments, as it reduces the need for multiple incisions and minimizes the risk of soft-tissue complications.

Furthermore, Wang et al.[5] and Bois and Dust[7] have shown that the modified posteromedial approach can be safely used to address posterior pilon fractures and posterior fracture-dislocations of the ankle, respectively.

Although the posteromedial approach primarily utilizes the window between the NVB and the FHL, Mitsuzawa et al.[8] demonstrated in an anatomical study that the tension over the NVB generated by soft-tissue retraction with the modified posteromedial approach is lower compared to the posterolateral or the classic posteromedial approach.

There are some limitations of our study that deserve to be highlighted. The primary limitation is the lack of a comparative analysis with other surgical approaches, which would provide a more comprehensive understanding of the relative advantages and disadvantages of the modified posteromedial approach. Additionally, this is a technical note with limited evidence, requiring long-term follow-up and larger sample sizes to adequately evaluate the true benefits of a single posteromedial approach to address both posterior and lateral malleolar fractures. Despite recommending the proximal extension of the skin incision to prevent skin necrosis and excessive traction on soft tissues, such complications may still occur. Furthermore, the literature requires confirmation of the hypothesis that the rehabilitation process is indeed easier with posteromedial approaches than with posterolateral ones, particularly in achieving dorsiflexion of the ankle.

However, one of the key strengths of our study is the detailed technical description of the single modified posteromedial approach for combined posterior and lateral malleolar fixation. Potential benefits of this technique include avoiding the need for an isolated lateral approach and mitigating the disadvantages associated with the posterolateral approach, particularly its limitations in addressing posteromedial fragments[9-13]. In addition, proximal extension of the skin incision may facilitate exposure and reduce the risk of complications from excessive soft-tissue traction. As previously mentioned, the modified posteromedial approach also appears to provide a more favorable angle for reducing impacted posterior malleolar fragments[9-13].

Conclusion

We describe the use of a single modified posteromedial approach in a limited clinical scenario. In this case, the approach allowed adequate visualization and reduction of the fractures while avoiding additional surgical incisions. However, given the nature of this report and its inherent methodological limitations, these findings cannot be generalized. Future studies with larger sample sizes and comparative analyses are needed to further validate the safety and efficacy of this promising technique.

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Aproveitamos o lançamento deste primeiro número de nossa revista em 2026 para lembrá-los da determinação da CET-ABTPé com relação à manutenção do credenciamento dos Centros de Aperfeiçoamento.

> ### Secção II – Manutenção do Credenciamento
>
> Art. 29° - Os centros formadores para Membro Titular ABTPé deverão publicar ou ter aceite de 1 (um) artigo científico por ano na revista **Journal of the Foot and Ankle** (eISSN: 2675-2980).
>
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O **Journal of the Foot and Ankle** adota um fluxo de avaliação e revisão das submissões que demanda alguns passos e tempos que devem ser respeitados não sendo passíveis de supressão ou aceleração. Por isso, é muito importante submeter os trabalhos ao JFA o quanto antes para evitar atropelos relativos aos prazos de concursos e exames.

Não perca a oportunidade de publicar seus artigos conosco.

Não deixe esse importante compromisso para depois!!!

Caio Nery
Editor-Chefe
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