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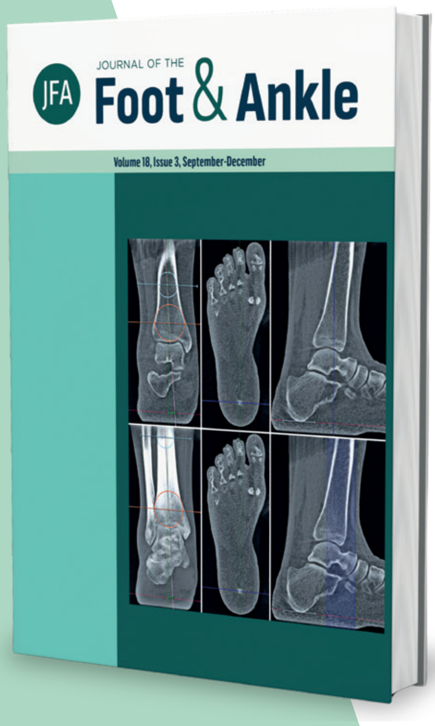

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Case Report

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JOURNAL OF THE FOOT AND ANKLE

Continuous publication: a step ahead in scientific communication

Starting in 2025, the Journal of the Foot and Ankle will adopt a continuous publication model, an innovative trend in scientific publishing that has been transforming how knowledge is disseminated. This model allows articles to be published immediately after editing without waiting to complete a specific issue or volume.

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Special Article

Pilon Fractures: Update on treatment

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Abstract

Tibial pilon fractures (plafond) are severe injuries resulting from predominately axial impaction. They are typically accompanied by severe damage to the vulnerable soft tissue envelope and the articular damage, making these fractures prone to complications. Treatment is individualized to the three-dimensional pathoanatomy, soft tissue damage, functional demands, compliance, and comorbidities of the affected patient. Most pilon fractures will benefit from stage management, which consists of primary closed reduction via ligamentotaxis, external fixation, and secondary internal fixation after soft tissue consolidation. In the hands of an experienced team with all resources available, primary definite internal fixation seems to be associated with similar results and complication rates but faster rehabilitation. Primary fixation of the fibula is rarely helpful, and definite fixation is not necessary in every case. The choice of approaches is guided by the individual fracture pattern, which ensures minimal soft tissue and periosteal dissection. Minimally invasive techniques should be employed whenever feasible. The goals of pilon fracture treatment are anatomic reconstruction of the joint surface and stable axial realignment towards the tibial shaft, bridging any metaphyseal comminution with the least possible amount of soft tissue and periosteal stripping. The choice of implants, particularly the number of plates, should be balanced between absolute stability on one side and preservation of the blood supply to the bone and soft tissues and the chance of callus formation for faster bone healing on the other.

Level of evidence V; Experience-Based Expert Opinion.

Keywords: External fixators; Minimally Invasive Surgical Procedures.

Introduction

There are various definitions concerning the concept of "pilon fracture" (pilon = French for "pestle"); however, there is a general agreement that the correct definition is a distal tibial fracture that involves the weight-bearing zone of the ankle joint surface (plafond = French for "roof"), extending into the tibial metaphysis[1-6]. Both terms-pilon and plafond-are used interchangeably in the literature. Pilon fractures represent 1% of lower limb fractures and must be understood as a wide array of osteoarticular, metaphyseal, and soft tissue injuries; this is why managing this fracture remains a challenging and complex issue for clinicians[7]. In general, these are high-energy injuries that occur in young patients, and the typical mechanism involves axial compression combined with shearing forces. The classical fragment pattern that develops after the talus impacts the distal tibial and the location and extent of articular comminution are determined by foot position[7-9]. Unfortunately, the prognosis of this injury is not encouraging, often resulting in life-altering disability and reduced quality of life[10].

As with any intraarticular fracture, the goal of operative treatment of pilon fractures is to achieve an anatomical reduction of the joint surface and axial alignment. However, this task is challenging due to the frequent encounters of significant comminution. Even with direct visualization or conventional fluoroscopy, non-anatomical reduction may occur, negatively affecting outcomes[10]. In a study by Vetter et al.[11], 43 out of 143 patients (30%) underwent correction

Study performed at the Clinica Guadalupe, San Juan, Argentina.

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after an intraoperative computed tomography (CT) scan due to inadequate joint line reduction[11]. Nevertheless, adequate reduction has not always translated into good functional outcomes, which can be explained by the damage to bone, cartilage, and soft tissues caused by the initial trauma[12,13].

Classification

Rüedi and Allgöwer[14] described the first radiographic pilon fracture classification[14]. These authors classified them increasingly according to severity; however, only poor agreement and reliability have been reported[15,16].

The Arbeitsgemeinschaft für Osteosynthesefragen (AO) introduced a widely used classification system with higher reliability and moderate agreement between observers. It has also been adopted by the Orthopaedic Trauma Association (OTA), and the distal tibial segment is collectively assigned the number 43. Fractures are divided according to the AO system into types A (extraarticular), B (partial articular), and C (complete articular). Further subclassification describes the amount of fragmentation[17,18]. It is easy to use and has a good prognostic value, but when used alone, it does not provide enough information on the morphology of the fracture for precise preoperative planning[19-21].

Urs Heim identified up to six main articular fragments regularly seen on CT scanning in AO type C pilon fractures, which are most useful for preoperative planning[22] (Figure 1). Leonetti and Tigani described a CT-based classification as reliable and reproducible, with high inter and intraobserver agreement. Each degree of severity in their classification correlates inversely with the American Orthopaedic Foot & Ankle Society (AOFAS) score[23]. This classification is based on joint involvement, displacement, number of fragments, the reference fracture lines, and the areas of comminution ranging from type 1 (a nondisplaced fracture) to type 4 (more than four fragments and significant comminution)[23].

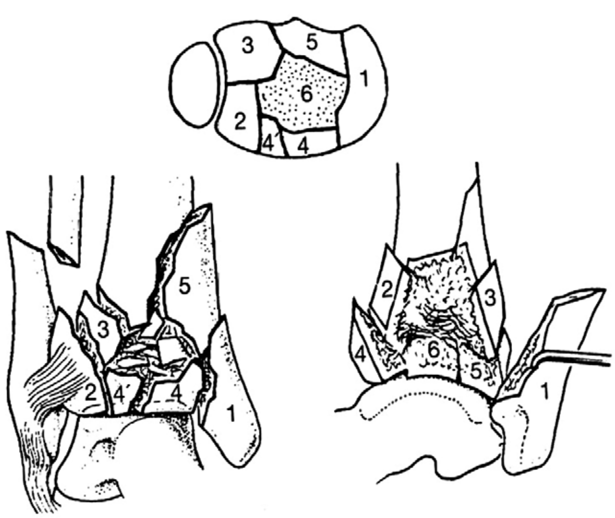

Figure 1. The main fragments of a comminuted C3 pilon fracture that can be regularly identified are, according to Heim [H]: 1 medial malleolus; 2 anterolateral (Chaput); 3 posterolateral (Volkmann); 4 anterior; 5 posterior; 6 central impacted (die punch) fragment(s).

Cole et al.[24], when analyzing the course of intraarticular fracture lines in axial CT scans ("pilon map"), described a constant Y-shaped fracture configuration in the AO/OTA 43C3 with a base of the Y at the fibular notch[24]. These authors identified three main fracture fragments, anterolateral, posterolateral, and medial, with the comminution area located centrally or in the anterolateral quarter of the plafond[24]. Similarly, Korrapati et al.[25] identified three typical fragments, anterior, posterior, and medial, with the "Y" shape being the most frequent configuration[25]. Additionally, they found that the central area is the most common depression site[25]. Assal et al.[26] developed a three-column model of medial, lateral, and posterior tibial pilon fractures, which find their expression at the joint level in the above-described three main fragments[26]. Chen et al.[27] later developed this into a four-column theory by including the fibula as a lateral column[27]. The involvement of each column is related to the foot position at the time of the initial trauma. It has to be noted, however, that none of these models consider the frequently encountered central impacted ("die punch") fragments essential for reconstructing the articular surface.

In AO/OTA type B fractures, the distinction between posterior pilon and posterior malleolar fractures with joint impaction is merely a matter of convention[28]. In posterior pilon fracture, the transverse fracture line runs anterior to the intermalleolar line, and the medial malleolus is fractured as a whole. In contrast, in posterior malleolar fractures, the fracture line runs posterior to the intermalleolar line and into the intercollicular groove of the medial malleolus in Bartoníček-Rammelt type 3 fractures or behind the posterior colliculus in Bartoníček-Rammelt type 4 fractures[29]. Rammelt et al.[30] also described a fracture at the anterolateral distal tibia (tubercule the Chaput, anterior malleolus type 3) with joint impaction[30]. In analogy to the posterior pilon fracture, an anterior pilon fracture would run posterior to the intermalleolar line and/or extend medially into the medial malleolus[31]. It has to be noted that there is a "grey zone" between those entities because both anterior and posterior malleolar fractures are frequently the result of combined rotational and axial impaction forces producing these "pilon variant" fractures[30,32].

Initial management

In most cases, the standard of care for this complex injury with critical soft tissue conditions consists of a two-stage approach, with temporary external fixation for damage control and an open reduction and internal fixation (ORIF). This method has significantly reduced the incidence of soft tissue complications and infections compared to earlier studies with early total care for all patients[33,34]. The objectives are early closed reduction, restoring the length, rotation, and alignment of the limb while providing an optimal environment for soft tissue recovery[12,35,36]. During the initial management, we do not recommend performing definitive treatment on the fibula because malreduction could jeopardize the overall fixation strategy and require revisions during definitive treatment.

After confirmation of the diagnosis by plain radiographs (Figure 2), the sequential management of this injury should be "span, scan, and plan" with meticulous soft tissue care[37] :

1. Span: Joint spanning external fixation, for instance, using a delta frame construct with two parallel pins in the tibial shaft (Figure 3). The superior Schanz screw should be placed a few centimeters distal to the tibial tubercle avoiding the metadiaphyseal extent of the fracture, another Schanz screw into the posterior tuberosity of the calcaneus (alternatively into the talar neck), and the last one in the first metatarsal base or the medial cuneiform to avoid equinus[38]. This construct has demonstrated the lowest relative micromovement during simulated gait in a biomechanical study[39].
2. Scan: A CT scan, including three-dimensional (3D) reconstructions, is essential to gain adequate insight into fracture patterns, allowing optimal surgical planning[40] (Figure 4). Tornetta et al.[41] reported that, after evaluating the CT scans, 64% of surgical plans had changed in their patient cohort[41]. Keiler et al.[42] identified that CT scanning should include 3D reconstruction, as it has shown greater inter and intraobserver reliability regarding the Rüedi-Allgöwer and AO/OTA classifications and a greater agreement for surgical planning between observers when compared to two-dimensional multiplanar CT[42]. We also recommend postoperative CT scanning to accurately evaluate the quality of reduction and the eventual need for early revision.
3. Plan definitive fixation: The choice of approaches, sequence of reduction, and fixation is planned with 3D analysis of the CT scans after closed reduction and external fixation. The soft tissue conditions dictate the timing of definitive fixation. Blisters, as reported in up to 25% of cases, may lead to changes in surgical planning, delays in definitive fixation, and infection[43]. Blisters indicate the energy of the trauma, as an association has been reported with AO type 43C fractures[25]. These cases have been reported to take 14 days to provide an optimal environment before definitive surgery, compared to 7.9 days for patients who did not have blisters[25]. In open fractures, negative pressure wound therapy is highly encouraged to create a more favorable environment for definitive fixation[44]. Multiple authors have reported two safe time frames for definitive

Figure 2. Anteroposterior and lateral radiographs of a 51-year-old male patient who suffered a motocross injury showing a type C pilon fracture with obvious metaphyseal and intraarticular comminution and a two-level fibular fracture.

Figure 3. External fixation with the delta frame configuration.

fixation: within the first six hours post-injury and between six to 12 days post-injury[45,46]. However, complications during both periods have also been reported[45,46]. Skin wrinkling signs reliably indicate edema subsidence and timing for definitive surgery[44].

Approaches

The approaches should be defined according to the fracture pattern, the reference fragment, and the location of the greatest displacement. The principal approaches described in the literature are:

1. Direct anterior (midline): This approach allows complete visualization of the distal tibia and versatile hardware positioning[47]. It is centered over the ankle and slightly curved, distally towards the talonavicular joint. After the skin incision, care is taken to spare the superficial peroneal nerve that crosses the wound from the lateral side distally[48]. Then, the extensor retinaculum is incised, and the anterior tibial tendon is retracted medially, while the extensor hallucis longus tendon with the deep neurovascular bundle is retracted laterally. Proximally, the approach can be extended following the lateral border of the tibial crest[48].
2. Anterolateral (Böhler's approach): This approach is preferred for C3-type injuries with a small or comminuted Chaput fragment. The patient is placed in the supine position, and the approach is made between the tibia and fibula, extending distally for approximately 4 cm while taking care to identify the lateral branch of the superficial peroneal nerve. The structures of the anterior compartment and the neurovascular bundle are retracted medially with the extensor tendons, and a lateral arthrotomy is performed[49]. The reported complications include injury to the peroneal nerves and anterior tibial neurovascular bundle, while it reportedly has the lowest amputation rate and a higher rate of radiographic consolidation compared to the anteromedial approach[50,51].
3. Anteromedial: This approach begins 4 cm proximal to the tibiotalar joint, medial to the tibial crest, and can be extended distally in the same manner as the direct anterior approach. It allows only poor visualization of the Tillaux-Chaput fragment and is associated with high complication rates compared to the anterolateral approach, particularly a significant increase in deep, superficial infections and nonunion[52,53]. The anteromedial approach may be modified, starting 10 mm distal to the medial malleolus and extending proximally, crossing obliquely to the lateral border of the tibia. It then curves to 105º-100° proximally, 10 mm lateral to the tibial crest[46].
4. Lateral: A standard lateral approach will fix an associated distal fibular fracture if not fixed through a posterolateral

Figure 4. (A) Axial, (B) coronal, and (C) sagittal computed tomography scans show the main intraarticular fragments: 1 medial malleolus; 2 anterolateral; 3 posterolateral; 4 anterior; 5 posterior; and 6 a slightly impacted central impacted fragment. Not the irregular bone structure after a distal tibial shaft fracture 20 years ago (same patient as in Figure 2).

approach. This approach has a low risk of complications; however, care must be taken to avoid injury to the lateral branch of the superficial peroneal nerve at its proximal end. The exact position of the incision depends on the location of the fibular fracture and the approach(es) to the distal tibia.

5. Posterolateral: It is performed with the patient in the prone position, midway between the Achilles tendon and the fibula. The sural nerve that runs epifascially from central to lateral is identified in the subcutaneous tissue and gently mobilized medially with the lesser saphenous vein[54]. Then, superficial and deep crural fascia are incised, and the posterior tibia and fibula are accessed in the interval between the flexor hallucis longus and peroneal muscles, which can be retracted medially and laterally, respectively[48]. This approach is particularly useful as it allows for treating posterior pilon fractures associated with fibular fractures[29,55]. With careful soft tissue management, the reported wound complication rates and sural nerve injuries are low in the treatment of posterior pilon fractures due to the extensive overlying soft tissue envelope[47,48,56]; however, a systematic review comparing various approaches found the posterolateral to be associated with the highest rate of wound complications (23%), and the medial approach has the lowest reported rate of ORIF-related complications, infection, and wound dehiscence[53,57]. Compared to the posteromedial approach, the posterolateral allows a similar visualization of the posterior pilon plus access to the distal fibula without the risk of injury to the tibial neurovascular bundle[28].
6. Posteromedial: This is performed with the patient in the prone position and a cushion placed under the foot. The length depends on the metaphyseal-diaphyseal extent of the injury, starting 3 cm above the tuberosity of the calcaneus between the Achilles tendon and the medial malleolus, avoiding the peritendineum of the Achilles tendon. Deep dissection is continued in the interval between the tibial neurovascular bundle medially and the flexor hallucis longus tendon laterally. The tibiotalar joint and the fibular notch are partially exposed, and intercalary fragments are resected or reduced depending on size. Once correct reduction is achieved, it is fixed with Kirschner wires (K-wires), and then a buttress plate is applied with cortical or locking screws. It is crucial to assess the stability of the syndesmosis with either the hook test or external rotation test since although the literature supports that the reduction of the pilon fragment or posterior malleolus would be enough to restore it, in some cases, it remains unstable and requires fixation[3,58,59].

This approach allows for broad visualization of the posterior pilon, enabling the possibility of fixing both the posterolateral and posteromedial fragments, particularly in posterior malleolar fractures with joint impaction ("posterior pilon variant")[60]. This approach lies close to the tibial neurovascular bundle with a high risk of injury or at least irritation, while a low rate of sural nerve and peroneal artery injury is reported, which perforates the interosseous membrane 4 to 6 cm from the tibial plafond[61]. To avoid wound complications, a curved incision above the three main branches of the posterior tibial artery, the angiosomes of the medial and plantar calcaneal branch is required with meticulous preparation of a full-thickness fasciocutaneous flap[62]. This approach could also be performed in the supine position, with the patient's leg in a "4" position. This position allows for combining it with other approaches, such as the anterolateral, without turning the patient, resulting in a significantly shorter surgical time (107.5 minutes versus 141.9 minutes in one study) than the prone/supine group[59].

Multiple studies have compared various approaches to the tibial pilon. They must be interpreted cautiously due to the high variability of pilon fractures and associated soft tissue compromise, as well as varying surgical expertise with any individual approach. Ketz and Sanders[48] found a similar range of motion (ROM) and functional scores between anterior and posterolateral approaches[48]. In contrast, Wei et al.[63] reported that anatomical reduction was best achieved through the posterolateral approach, followed by the anterior, anteromedial, and anterolateral[53,63]. Chan et al.[64] found a higher nonunion rate in AO 43C3 fractures when a combined anterior and posterior approach was performed, while the reduction quality was similar when comparing the same type of fractures treated with only a single anterior approach[64]. In a comparative study on 590 pilon fractures, the authors found an infection rate of 19% with no significant association with any particular approach. Still, they identified the need for soft tissue coverage and smoking as independent risk factors for developing infection[65]. In a systematic review of 733 cases, Liu et al.[53] found the anterior approach to be associated with the overall best results despite a high proportion of type-C fractures[53].

It has been classically held that a 7 cm skin bridge must be maintained between different distal tibial approaches; however, this concept has been challenged[66,67]. Three vascular territories have been described, arranged vertically, supplying the overlying soft tissue envelope of the ankle. If the incisions are vertical and parallel, the distance between them does not matter, and there would be no threat to the resultant skin bridge[62,66-68]. In summary, the choice of approaches is individually tailored to the fracture pattern, avoiding excessive soft tissue dissection and periosteal stripping, and has to consider the treating surgeon's expertise with any given approach.

Early primary fixation

Several authors have supported the definitive treatment of pilon fractures at an early stage[37,69,70]. This perspective is based on the understanding that prolonged delays in surgery may lead to less effective anatomical reduction and an increased risk of postoperative infections[69]. Additional considerations are that spanning external fixation restricts early movement, which can result in ankle stiffness and inadequate cartilage nutrition[12]. Further concerns include complex regional syndrome because of delayed definitive surgery and pin-track infection[12]. White et al.[37], in a series of 95 patients with AO/OTA 43C fractures, reported good outcomes and high-quality reduction with early primary ORIF within 48 hours of injury, with only 6% of deep infections[37]. Tang et al.[70] compared early definitive fixation with minimally invasive techniques in 23 patients treated within 36 hours after injury vs 23 patients managed with a staged protocol, finding no significant differences between the groups regarding soft tissue complications, fracture union, and functional scores[70]. Additionally, these authors noted an increase in mean operative time, union time, costs, and hospital stay in the delayed surgery group, concluding that early ORIF is a safe procedure comparable to the staged protocol when soft tissue conditions are acceptable[70]. Several recent studies found that early primary fixation compared favorably with a staged protocol in the hands of fellowship-trained orthopedic and trauma surgeons[71-73].

Several authors have identified a window between three and five days post-injury when soft tissue swelling is highly increased, suggesting that early ORIF should be performed during the first two days to prevent wound complications[74].

Early definitive ORIF requires the availability of an experienced team and operation room resources within 48 hours of the injury. The same principles for planning approaches, reduction, and fixation apply to staged protocol management. If these conditions are not met, primary closed reduction, external fixation, and patient transfer to an institution with adequate expertise will help avoid severe complications.

Surgical strategies

Many strategies for the reduction and fixation of pilon fractures have been proposed in the literature, mostly based on the principles by Rüedi, Allgöwer and Heim with numerous modifications[18]. There is poor evidence on the ideal approach because of the great variability of pilon fractures and associated soft tissue damage. Some general considerations will be discussed in the following.

The individual choice of approaches and fixation depends on the quality of the soft tissues and the major fracture pattern. Stable internal fixation of the three main pillars (columns) of the tibial plafond and centrally impacted fragments should be pursued in a 360-degree manner and may be achieved with even a single plate, depending on the individual plate design[26,75]. The use of dual or triple plates should be weighed against the cost of extensive soft tissue dissection, unnecessary periosteal stripping, and compromise to the blood supply of the distal tibia with the risk of nonunion and osteonecrosis[75-79]. Likewise, fixation of the distal fibula as a "fourth column" is not generally indicated and may even negatively impact the reduction and healing of the tibia fracture[79,80].

By anatomically reducing the joint surface first, a complex type C3 fracture can be simplified to a type A fracture (Figure 5), while in less complex intra-articular fracture patterns (type C1/2), the fracture may be converted into a type B fracture by fixing the larger joint-bearing fragment to the

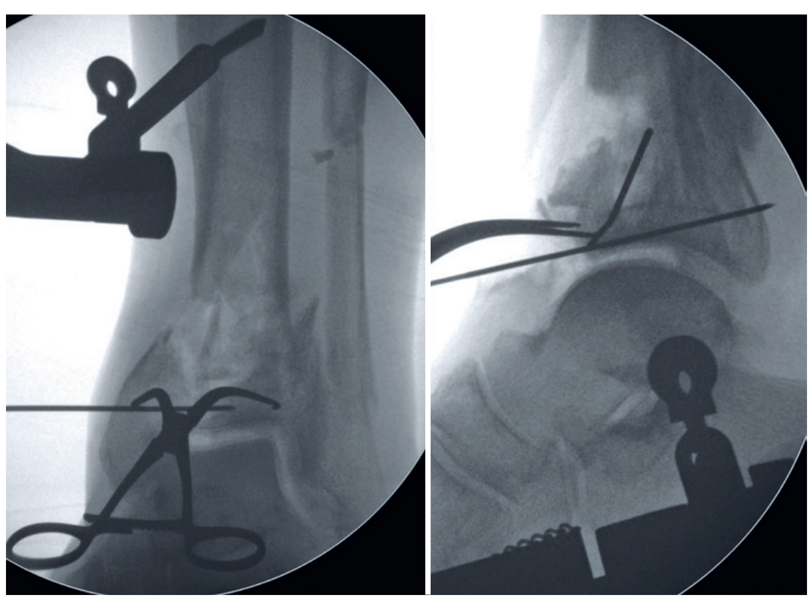

Figure 5. A central anterior approach is used for direct access into the main fracture line between the anterolateral and anteromedial fragments (same patient as in Figures 2-3). For complex articular fractures of the tibial plafond, starting with the joint reconstruction is useful, turning a type C into a type A fracture as long as all fragments are mobile. The tibial and calcaneal pins of the external fixator are draped free and may be used for joint distraction for both ligamentotaxis and enhanced overview over the joint surface. The tibial plafond is reconstructed step-wise from posterior to anterior and lateral to medial. The reduced fragments are temporarily held with pointed reduction clamps and Kirschner wires.

tibial metaphysis[18]. In type C3 fractures, there is no place for indirect reductions, and each fragment must be addressed through open reduction and direct visualization.

During reduction, it is important to consider displacement of the peroneal tendons (as reported in 90.9% of cases in a CT study), along with entrapment of the posteromedial flexor tendons and the posterior tibial neurovascular bundle as seen in approximately 10% of cases to avoid poor reduction of the fracture, impaired tendon function, and neurovascular injury[81,82].

An anterior approach is often used to reduce the joint pressure under direct visualization. One tibial and calcaneal Schanz screw from the external fixator may be kept in place to be used for distraction to gain a complete insight into the fractured tibial joint surface (i.e., by using a femoral distractor- see also Figure 5). The exact position of the approach (anteromedial vs. central vs. anterolateral) is chosen close to the main anterior fracture line to minimize soft tissue dissection and periosteal stripping. The anterolateral and anteromedial fragments are gently separated, and the central, posteromedial, and posterolateral fragments are identified. The latter may be considered a constant reference fragment for starting the reconstruction from posterior to anterior and lateral to medial[52]. Distraction can be relieved, and the talar dome is used as a template for realigning the central impacted (die punch) fragments[18]. Reduced articular fragments can be temporarily fixed with K-wires that may be driven out posteriorly. The anterolateral and anteromedial fragments are then reduced to the posterior and central fragments, and the K-wires are driven back from posterior to anterior, thus completing the reconstruction of the joint surface and turning the type C into a type A fracture. The K-wires may be exchanged with independent screws or resorbable implants. Small articular fragments may be cut flush with the anterior and posterior cortex and left in situ as "lost K-wires." Lag screws should only be used for simple fracture patterns. After joint reconstruction, the metaphysis is stabilized to the diaphysis with plate(s) and screws adapted to the individual fracture pattern and soft tissue conditions (Figure 6). If the main fracture line runs in the frontal plane, it is mechanically superior to place the plate anteriorly or posteriorly on the tibia[48]. If the main fracture line is situated in the sagittal plane, it is preferable to put the plate on the medial side to position the screws perpendicular to the fracture line.

Autografts or allografts may be utilized for larger defects resulting from bone loss or extensile metaphyseal comminution, although clinical evidence does not support it[83].

If a posterior approach is chosen, fixation of the posterior pilon is ideally performed with a posterior buttress antiglide plate. If a staged procedure is planned, care should be taken that the screws do not interfere with later anterior fragment fixation[48].

Definitive treatment

The principles of internal fixation are direct reduction and stable fixation of the articular surface, followed by restoration of metaphyseal length, rotation, alignment, and stabilization towards the tibial shaft spanning any comminuted metaphyseal fracture while minimizing any compromise to the soft tissues[84]. The options for definite fixation will be discussed in the following.

Intramedullary fixation

In diaphyseal comminution of the tibia with extension into the joint and poor soft tissue envelope, intramedullary nails (IMN) may be an option for internal fixation of simple articular fractures. The tibial plafond has to be fixed first with screws to avoid further fracture dislocation while introducing the nail. Joint reduction is controlled via a small, direct incision. If nondisplaced, the plafond fragments may be fixed with percutaneous screws. Marcus et al.[85] performed IMN in 23 patients with AO/OTA 43C1 fractures, achieving union at 14.1 weeks with excellent alignment, 8% infection, and 0% nonunion[85].

Goodnough et al.[86] described a reportedly safe technique that involves the use of a percutaneous, intramedullary screw placed from the medial malleolus, traversing the fracture site, with a bicortical tibial fixation on the contralateral side as medial support alongside less invasive anterolateral plate fixation in cases of fractures with metaphyseal involvement[86].

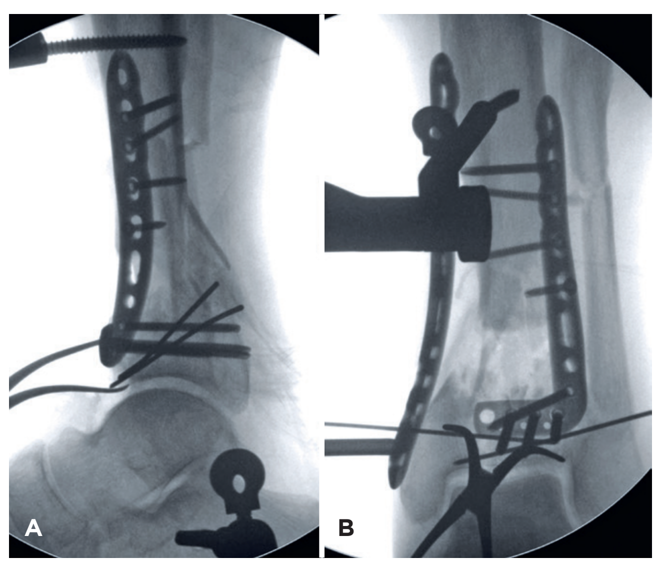

Figure 6. (A) Following joint reconstruction, the reconstructed joint block is aligned to the tibial shaft, and the metaphyseal zone of comminution is bridged by a locking anterolateral distal tibia plate that is slid in epiperiosteally and fixed in the proximal fragment via stab incision. (B) A medial buttress plate is introduced via minimal incisions in a minimally invasive plate osteosynthesis technique (same patient as in Figures 2-4).

Plate fixation

Many designs of pre-contoured distal tibia plates for pilon fractures have been described[66,75]. The objective is to span the metaphyseal comminution, thereby serving the function of bridge plates and promoting secondary bone healing through callus formation via endochondral ossification[78,84]. Using two or more plates can negatively impact callus formation if the construct is overly rigid[78]. On the other hand, the absence of implants on the medial or lateral side of the tibia may result in a weaker construct, leading to secondary subsidence in the coronal plane[78,84]. Campbell et al.[78] identified that placing one plate provides more callus formation at six months than dual plate fixation in a study of 50 patients with AO/OTA C2 or C3 fractures without impacting the reoperation rate[78]. Various authors have pondered whether the placement of these plates and their respective screws would be capable of stabilizing the three reference fragments (anterolateral, posterolateral, and medial). In a study using synthetic distal tibia sawbones, Penny et al.[75] demonstrated that three of four available anterolateral plates lacked stable fixation in the medial fragment with at least two screws. On the other hand, medial plates did not stabilize the anterolateral and posterolateral fragments with at least two screws (which are considered necessary to prevent rotation)[75]. Only screw insertion through the anterolateral variable angle plate could stabilize all three fragments[75]. A similar study performed in bone models based on fracture patterns in 162 patients AO/OTA 43C3 comparing three different models of anterolateral plates concluded that none of the three models could fix the medial malleolar fragment, and the Volkmann fragment was missed in 1.2% to 3.6% of cases[87]. Lack of medial support may lead to late varus deformities and nonunions[88]. From the available data, it appears that the anterolateral plate is most important for buttressing the area of greatest comminution, and the screws inserted through a variable angle plate can fix the three main fragments. To create a stiffer construct, particularly in more complex fracture patterns, the addition of a second (medial) plate or independent screws should be considered depending on the fracture pattern (Figure 6).

If possible, further damaging already compromised tissue plates should be inserted in a minimally invasive plate osteosynthesis (MIPO) technique to avoid extensive soft tissue and periosteum dissection. Alignment, length, and rotation of the distal tibia can be restored through indirect fracture manipulation of the diaphyseal and metaphyseal region, resulting in the preservation of periosteal blood supply and a lower rate of complications[89]. Extraarticular intercalary fragments are indirectly reduced without being stripped of their blood supply, thereby preserving bone biology. Percutaneous plates introduced and fixed via stab incisions may be useful on the medial aspect of the tibia due to less disruption to the extraosseous blood supply[12,90]. In a systematic review, it was reported that through the MIPO technique, an 87% rate of excellent to good results was achieved, comparable to ORIF, with a complication rate of 35%, including superficial infections (4.3%), only one case of deep infection, nonunions in 0.6%, and malunions in 3.%. and adequate quality of reduction[91]. A purely MIPO technique should be reserved for selected pilon fractures with a predominance of large fragments without substantial articular comminution[18]. Typically, the anterolateral plate is placed through an anterior incision that is also used for an anatomic joint reduction but slid in proximally bridging the zone of metaphyseal comminution, and the proximal screws are inserted into the diaphysis via stab incisions, while a second, medial plate, may be introduced in a MIPO technique (see Figure 6)[18,92].

External fixator

Keeping an external fixator as definitive fixation should be reserved for patients with significant wound compromise, bone loss, severe underlying comorbidities, infections, or unreconstructable injuries. In this case, the objective is to restore a functional limb while minimizing the risk of further complications[36]. Ideal indications are low fractures with minimal metaphyseal extension, partial articular fractures, and non-comminution[36]. To add additional construct stability, fixation with two mini-fragment plates has shown sufficient reduction maintenance over time[75].

The main advantages are a lower infection rate; however, complications such as articular malreduction, metaphyseal malalignment, ankle stiffness, loss of reduction, and malunion have also been described, leading to inferior outcomes compared with standard open reduction and internal fixation[45,93]. Richards et al.[94] compared 60 patients treated with ORIF vs. definitive external fixation with no difference in the quality of articular reduction. Delayed union and nonunion were more frequent in the external fixation group, and Iowa Ankle Scores and The 36-Item Short Form Health Survey (SF-36) scores were better in the ORIF group[94]. Zhao et al.[95] assessed 21 type C pilon fractures treated with an external fixator combined with limited open reduction and absorbable internal fixation. The results were satisfactory, with a union time of 4.8 months, superficial infection in eight patients, deep infection in one but no malunion, loss of reduction, or nonunion[95].

Another option for this complex injury is a circular external fixation with small wire or hybrid fixators. This construct allows for injury management with less soft tissue disruption and early weight bearing, also offering the possibility to perform gradual correction after initial surgery[36]. When using a circular small wire frame, an ankle sparning construct may be employed to allow for early motion[96]. In simple intraarticular fracture patterns, percutaneous joint reduction may be controlled arthroscopically[96]. Bacon et al.[97] did not find statistically significant differences in malunion, time to union, infection, or complication rates in pilon fractures treated with an Ilizarov frame or open plating[97]. Bastías et al.[33] compared 30 patients who received traditional ORIF vs 23 patients who underwent hexapod ring fixation for AO/OTA 43C3 pilon fractures; minor complications such as superficial infection and malalignment were significantly higher in the hexapod group; however, the ORIF group had higher major complications such as deep infection[33]. Other reported complications by these authors, such as nonunion, reoperations, or ankle osteoarthritis, were not significantly different between groups, concluding that using the hexapod fixator, patients could achieve high union rates associated with low complications[33]. External fixation remains a troubleshooter in any case of poor soft tissue conditions or any complication requiring the removal of all internal fixation.

Primary arthrodesis

Irrespective of the type of ORIF, pilon fractures carry an inherent risk of early osteoarthritis with chronic residual pain due to articular comminution with severe chondral damage, soft tissue damage, and bone stock loss[7,98]. Age should not be a determining factor when deciding between arthrodesis and ORIF, as patients over 60 have shown similar results in treatment failure, bone loss, and malreduction compared to young patients[99]. Zelle et al.[100] performed ankle arthrodesis with a posterior blade plate on 17 patients with AO/OTA C2 and C3 who presented more than 50% impaction and extensive comminution with results comparable to patients undergoing ORIF. They reported neither deep infections nor malunion, with union achieved at 132 days[100]. Nicholas et al.[101], in their systematic review, found that primary ankle arthrodesis yields reasonable results in pilon fractures; however, only eight studies with 109 patients were eligible for the review, and many of them had inadequate follow-up[101]. Beckwitt et al.[102] reported even better Foot and Ankle outcome scores (FAOS) after primary arthrodesis than ORIF[102]. Arthrodesis can be performed using an anterior plate, a posterior blade plate, an external fixator, or an intramedullary nail [100,103]. Using an external fixator provides long-term stable fixation with a low risk of infection (apart from pin-tracks), allowing distraction osteogenesis in case of significant bone loss[104]. Solid fusion was achieved in one study at nine months in 12 of 14 patients (nine were talus fracture-dislocations) using a hexapod (Taylor Spatial Frame) external fixation with good results (SF-36 of 65, Ankle Osteoarthritis Score (AOS) 36.5 with 69.3% of scores graded good to excellent) without developing deep infection[105]. Arthrodesis using a retrograde intramedullary nail allows stable hindfoot fixation through minimally invasive incisions, thus avoiding potential wound complications, but additionally sacrifices the subtalar joint[106]. The inherent disadvantages of arthrodesis compared with joint-preserving procedures are decreased gait velocity, cadence, and stride length[107].

Open pilon fractures

The rate of open pilon fractures has been reported to be as high as 20%[108]. This relatively high incidence is due to the thin and vulnerable soft tissue envelope surrounding the distal tibia, which is susceptible to disruption with injury[109]. Such a scenario is challenging and is associated with a 10.5% to 18.8% risk of deep infection[44,110]. However, if an appropriate treatment based on aggressive irrigation and debridement is followed by early soft tissue coverage, low nonunion rates, and infection could be achieved[3].

The classic protocol for open fractures includes debridement of devitalized bony and associated soft tissue followed by ankle-spanning external fixation. Lim et al.[9] treated 20 patients with open pilon fractures managed through early wound debridement, spanning external fixation (delta or rectangular frame), delayed soft tissue coverage with a flap when necessary, and delayed definitive fixation using a fine wire fixator (Ilizarov or Taylor) once the soft tissue was sufficiently healed[9]. Bone union was achieved in 19 patients at a mean time of 10.4 months. The AOFAS score at 12 months was 74.2, with a 50% incidence of post-traumatic arthritis due to anatomical reduction in only 50% of the cases[9]. The reported nonunion rates after open pilon fractures are also significant, ranging from 6% to 42%[3]. Olson et al.[111] compared patients who suffered AO/OTA 43C fractures treated surgically within 24 hours (36 patients) with those treated after more than 24 hours (125 patients). The incidence of open fractures in their cohort was 22%[111]. They reported a 27% rate of deep infection and a 22% rate of nonunion, with a statistically significant correlation between both variables. Their results indicated that patients who underwent early surgical intervention and presented with an open fracture Gustillo Anderson type 3A had a higher infection rate. The authors concluded that definitive treatment should not be performed during the initial management of an open fracture; rather, a staged protocol should be preferred. The same group identified factors such as male sex, smoking, connective tissue disease, and Gustilo Anderson type 3B fractures as associated with a higher infection rate[111]. Siluzio et al.[3] reported a mean AOFAS score of 71.5 at 12 months in 14 patients who sustained AO/OTA 43C open pilon fractures (Gustilo Anderson 3 A-C), with 28% deep infections, 43% superficial infections, and 43% delayed union after staged management[3]. In cases where the soft tissues do not allow for primary closure, negative pressure wound therapy can be useful until the inflammation subsides and a delayed closure or eventual flaps or grafts can be planned[112]. Temporary placement of an antibiotic cement spacer is a useful adjunct in cases of bone loss during the initial trauma, as it fills the defect, creates an antimicrobial local environment, and a vascularized envelope for further grafting ("periost-like membrane")[113]. Factors that predict soft tissue complications include falls from a height greater than 3 meters, segmental fibular fractures, and multifragmentary articular tibial fractures. These factors suggest that the higher the energy involved in the injury mechanism, the greater the potential for soft tissue complications[114].

Posterior pilon fracture

Fractures of the posterior tibial rim have a 46% association with Weber B or C distal fibular fractures[115]. The term posterior malleolus (or posterior pilon) is defined based on whether the fragment involves up to (or more than) 50% of the tibial incisura and whether the medial malleolus is fractured in the intracollicular groove or as a whole[28]. Regardless of this definition, fixation of the posterior tibial fragments is crucial to restoring syndesmotic integrity, the tibiofibular incisura, thus facilitating anatomic reduction of the distal fibula[29,116]. Failure to reduce posterior fragments has been related to persistent posterior talar subluxation[117]. Attempts to fix the posterior malleolus through indirect reduction or fixation will likely yield non-anatomic reduction and poor results[29]. These results were supported by Ketz and Sanders[48], who performed staged posterior tibial plating for posterior malleolar fractures associated with 43C2 and 43C3 pilon fractures[48]. In nine cases, they performed a posterolateral approach for the posterior malleolus and a secondary anterior approach for the pilon fracture through a standard anterior midline incision, averaging 18.5 days apart. During this time, the fractures were temporarily stabilized with an external fixator, and another CT was performed to assess the quality of reduction and fixation of the posterior fragment(s). The quality of reduction and functional outcome were superior to ten patients in whom an anterior or anteromedial approach was utilized for the pilon fracture, along with an indirect reduction of the posterior malleolus fracture[48]. However, the overall number in both groups was small, and in a follow-up study from the same institution with 116 patients, of whom 35 underwent staged fixation of the posterior malleolar component, there was no statistically proven benefit regarding the quality of articular but a significantly higher risk of nonunion associated with multiple (posterior-anterior) approaches compared to a single (anterior-alone) approach[64]. Besides posterolateral (or posteromedial) approaches, the posterior malleolus component can also be reduced via a trans-fibular approach, providing direct visualization if the fibular fracture is in line with the posterior malleolar fracture, which is rather the case in rotational injuries and less common in pilon fractures[55].

Unlike classic tibial pilon fractures resulting from axial impact, isolated posterior tibial pilon fractures are considered lower energy and frequently occur in elderly patients[118-120]. In these cases, single posterior approaches will be performed, and the soft tissue cover in this region will result in a lower risk of wound dehiscence and infection[119,120].

What about the fibula?

Fibula fractures occur in more than 90% of cases of type C pilon fractures[121]. Its incidence is directly associated with a higher energy of the initial trauma[121]. Luk et al.[122] compared 36 tibial plafond fractures with an intact fibula against 71 pilon fractures in association with fibula fractures and stated that the group with an intact fibula was more commonly associated with AO type B patterns, and the group with pilon and fibula fractures was more associated with type C patterns[122].

Historically, reduction and fixation of the fibula in these types of fractures were considered fundamental to treatment success[14]. The objective was to achieve proper fibular length, alignment, and rotation to reduce the tibial plafond through ligamentotaxis and to prevent angular displacement in any plane by stabilizing the lateral column[123]. Other considerations for fixing the fibula included shortening, comminution, or distal fractures that would violate the syndesmosis[85]. In one study, the fibula length strongly correlated with the Foot and Ankle Ability Measure (FAAM) among 13 radiographic parameters [124]. Korkmaz et al.[1] reported that patients with an associated fibular fracture fixed with a plate had a statistically significant better range of ankle motion than those with unfixed fibula[1].

On the other hand, Kurylo et al.[125] found no statistically significant differences between 26 patients with fibular fracture fixation, 37 with fibular fractures unfixed, and 30 without fibula fractures in postoperative or final alignment, concluding that fixing the fibula is not always necessary[125]. In a similar study, Hong et al.[80] compared 25 patients who underwent fibular fixation with 29 patients in whom only tibial pilon fixation was performed. There were no statistically significant differences in outcomes or complication rates[80]. The authors concluded that fibular fixation is not necessary unless additional stability is desired or it aids in the reduction of the tibial pilon fracture[80]. If fibular fixation is performed, several authors recommend starting with fibular alignment in AO type 43 A or B pilon fractures, as there is no significant articular compromise of the distal tibia[83,125]. However, starting with the fibula should only be contemplated in simple fractures, where achieving adequate alignment, rotation, and length would facilitate tibial reduction[18]. With significant comminution of the fibula and all AO 43 C tibial fractures, there is consensus to begin with the reconstruction and alignment of the tibial plafond joint surface (Figure 7)[18].

Figure 7. The fibula is fixed last with a long plate bridging both fracture levels applied in a minimally invasive plate osteosynthesis technique (same patient as in Figures 2-5).

In summary, fibular fixation is not generally indicated in treating tibial pilon fractures. It may be considered individually in severe pilon fractures to maintain length and alignment of the tibia, to augment tibial fixation in case of poor bone quality, or to prevent soft tissue prominence of the displaced fibula[80]. During initial closed reduction and external fixation, primary fibular fixation may add to the soft tissue compromise, prevent proper manipulation of the distal tibia, or even interfere with the choice of approaches.

Syndesmotic injuries

Syndesmotic injuries and syndesmotic equivalent injuries, i.e., avulsions at the tubercule de Chaput or posterior malleolus ("Volkmann fragment"), have been reported in 3.4 to 25% of pilon fractures, particularly in those with bifocal fibula fractures[126-128]. Purcell et al.[128], in a retrospective study comparing pilon fractures with and without syndesmosis injury, concluded that this type of associated injury implies a higher energy trauma and can lead to a greater number of reoperations, neurovascular injuries, and even amputation[128]. Likewise, Christensen et al.[127] saw significantly worse outcomes in pilon fractures associated with syndesmotic injuries[127]. Haller et al.[126], in an analysis of 735 pilon fractures, found missed syndesmotic injury to be associated with the development of post-traumatic arthritis in 13 of 14 cases. In the same study, patients with a Chaput or Volkmann fragment greater than 10 mm significantly benefited from the fixation of these fragments[126]. Malposition of the syndesmosis, defined as > 2 mm difference in tibiofibular relationship to the uninjured side, is not uncommon (16 of 26 patients in one study) and was associated with inferior outcomes as measured by significantly lower FAAM and Activities of daily living (ADL) scores [129]. Like in complex malleolar fractures, restoring normal tibiofibular relationships, including anatomic reduction and fixation of syndesmotic avulsions in pilon fractures, appears essential for obtaining favorable results and avoiding post-traumatic arthrosis [129].

Aftercare

Following ORIF of closed pilon fractures, a well-padded posterior splint is applied, followed by a removable walker boot. Range of motion exercises are initiated after soft tissue consolidation. Patients are restricted to partial weight-bearing on two crutches in a walker boot for 8-12 weeks, depending on the individual fracture pattern, bone quality, and comorbidities. Patients who cannot walk on crutches are subject to non-weight-bearing in a wheelchair. In case of doubt about the quality of reduction and bony consolidation, CT scanning is employed (Figure 8). Regular weight-bearing radiographs are advised to assess fracture consolidation (Figure 9).

Complications

Because of the high trauma energy, the initial bone and cartilage damage due to the impaction, and the vulnerable soft tissue cover, complications are common in pilon fractures, including wound compromise, infection, nonunion, malunion, post-traumatic osteoarthritis (PTOA) and osteonecrosis[7,130]. PTOA is the most recognizable long-term disability, which has been reported in more than 50% of patients within four years after the injury[131,132]. The onset of early arthritis is directly related to poor anatomical reduction due to load transfer within the articular surface and is, in turn, associated with significant functional impairment[133,134]. This scenario is more frequent in pilon fractures treated with external fixation only[135]. If detected early, intraarticular osteotomies following the original fracture pattern could be performed in selected patients who are young and active, with good bone stock, compliance, and sufficient cartilage cover over the weight-bearing areas[136].

However, PTOA may also be caused by primary chondral damage due to axial forces during the initial trauma, despite further anatomical joint reconstruction[134,137]. DeCoster et al.[138] found reduction quality correlating with PTOA but not with medium-term functional outcomes[138]. Jo et al. demonstrated that pilon fractures associated with anterior impaction were significantly associated with advances in PTOA and anterior talar subluxation at 25 months compared to patients with other types of pilon fractures[139].

Willey et al.[140] found a 21% decrease in joint space in the injured ankle in weight-bearing computed tomography (WBCT) at six months in 20 patients who underwent ORIF for pilon tibial fracture, with the middle lateral and middle central regions showing the largest decrease[140]. Fortunately, radiological arthritis does not necessarily correlate with the same degree of symptoms, meaning that only about one-third of the patients may need further surgery like cheilectomy, debridement, joint distraction, ankle fusion, or total ankle replacement[136].

In the presence of early PTOA with focal defects no bigger than 1x1cm^2 after pilon fractures in young patients, osteochondral autograft in combination with ankle distraction and supra malleolar osteotomy in case of coronal malalignment may prevent rapid progression of osteoarthritis[141].

The use of external fixation does not preclude complications such as pin site infections in 20%[142], superficial infections in 6%[143], deep infection in 8%-17%[144], delayed bone union in 4%[145], inadequate union, nonunion, and initial loss reduction in 30%[146]. Lu et al. compared ORIF vs. external fixation, concluding that superficial infections were higher in the external fixation cohort than in the ORIF cohort; however, comparing those different patient cohorts should be viewed cautiously[147].

Nonunions are reported in 2-10% of cases and have been associated with fracture comminution, open fracture, soft tissue compromise, and smoking[148,149]. Treatment options include autologous bone grafting and augmentation of the construct using plates, nails, or external fixation[150].

Osteonecrosis is linked to certain fracture patterns, such as comminution, the presence of a small anterolateral fragment (< 2 cm^2), and the use of calcium phosphate bone substitutes[151]. One study identified osteonecrosis in 18 out of 69 patients at a follow-up of 7.3 months[151].

The most dreaded complication is a deep infection, which has been reported to occur in 2 to 16.7%[57]. Several risk factors for the development have been identified like Gustilo-Anderson type 3A or 3B open fracture, medial or anterior open wound, segmental bone loss or the need for soft tissue coverage, diabetes mellitus, comminuted fractures, smoking, male gender, advanced age, and high-energy trauma[57,73,152]. Correct soft-tissue management is critical to avoid the complications mentioned above, including a staged protocol, identifying the optimal window to perform

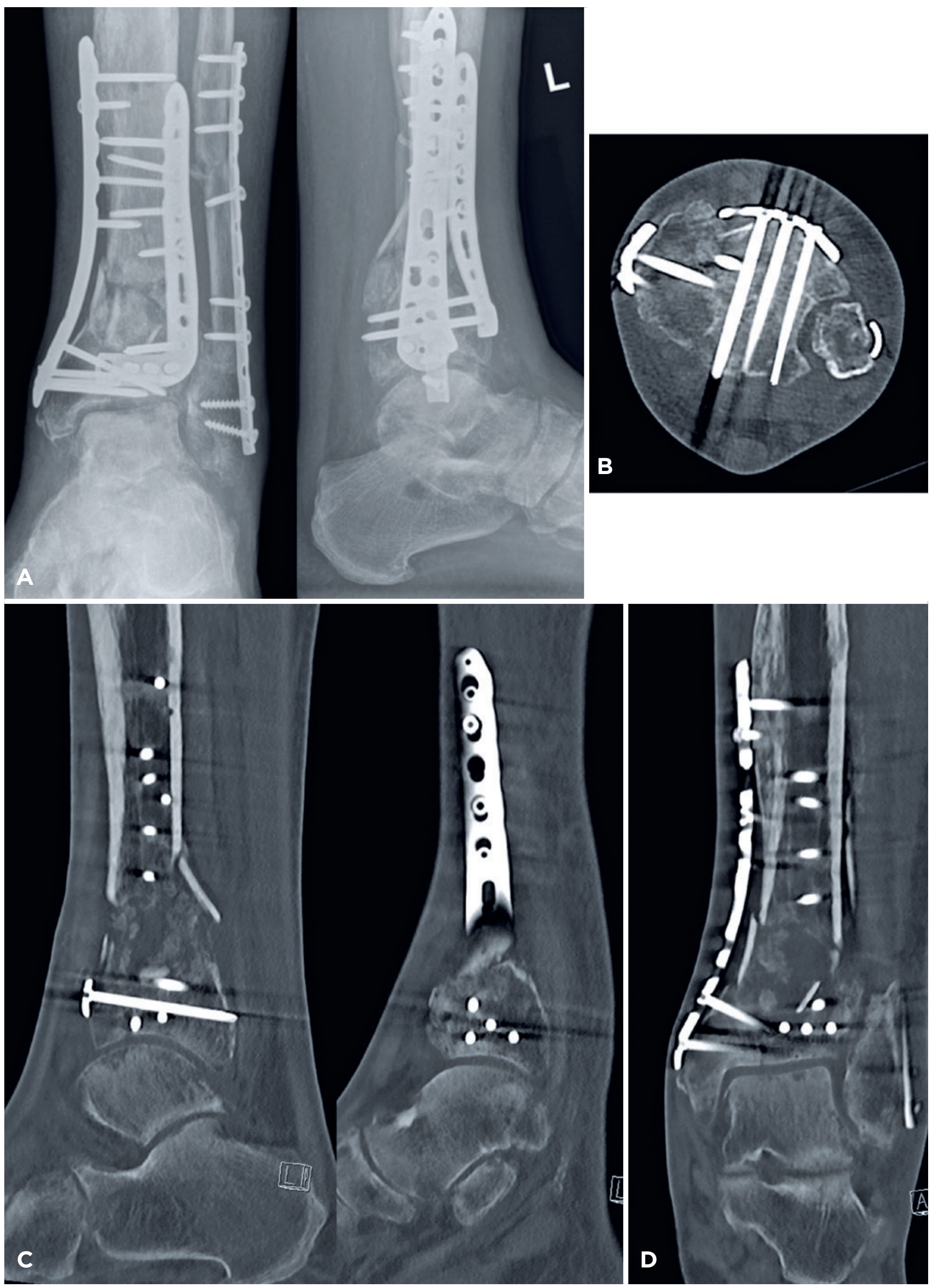

Figure 8. (A) Postoperative radiographs, (B) axial, (C) sagittal, and (D) coronal computed tomography scans showing anatomical restoration of the joint surface and the axial realignment to the tibial diaphysis (same patient as in Figures 2-6).

ORIF, avoiding aggressive reconstructive maneuvers, using atraumatic techniques, meticulous debridement, employing vacuum-assisted closure devices, and being reasonable and suspicious to anticipate potential wound dehiscence with timely intervention by plastic surgeons[12,147]. The amputation rate following a deep infection in patients with pilon tibial fractures has been reported with an incidence of up to 15%[152]. Using Vancomycin and Tobramycin powder appears promising in reducing infection rates in high-risk open and closed fractures, including pilon fractures[153,154].

Prognosis

Despite appropriate treatment, pilon fractures still routinely result in long-term dysfunction and pain. Several authors have reported swelling rates ranging from 29% to 76%, pain at 33%, and ankle stiffness from 31% to 66% after type C pilon fractures[155-157]. Most patients regain about 75% of their former functionality (Figure 10); however, 50% of them experience some level of disability, pain, and difficulty when walking, and 30% of them had to change their jobs[155-158]. Several conditions, such as diabetes or smoking, have been demonstrated to worsen the prognosis in the treatment of pilon fractures, affecting bone union and functional outcomes[159]. Uncontrolled diabetic patients have a 3.8 times increased risk for overall complications[160-162]. Wheelwright et al. identified factors associated with high performance after a pilon fracture, including lower body mass index, closed fractures, and AO 43B fractures. An 8% decrease in the odds of body mass index was related to high-performance patients with every unit increase[10].

In their study, Korkmaz et al.[1] evaluated different variables that could influence outcomes: fracture type (Rüedi/Allgöwer type 3), surgical treatment, and quality of reduction in 118 patients with pilon fractures (43B3, C1, C2, and C3) treated individually with different external and internal fixation methods[1]. The most important finding from this study was the statistically significant correlation between the quality of reduction and functional scores, independent of the type of surgery performed, which is confirmed by numerous other clinical studies[48,91]. For the same reason, several studies reported poor results with purely external fixation for type C fractures[97,135].

Pollak et al.[156] also assessed patients who sustained type C pilon fractures treated by ORIF or external fixation. These patients reported scores significantly lower than age-matched controls, even worse than patients with hip fractures or chronic illnesses such as AIDS, coronary artery disease, or diabetes[156]. As a consequence, tight control of blood glucose levels, adequate nutrition and vitamin substitution, and abstaining from alcohol, smoking, and drugs are important adjuvant concepts in the overall management of patients with severe pilon fractures[163].

Kellam et al.[155] reported that functional outcomes (PROMIS PF) after AO/OTA 43B/C pilon fractures improved from six weeks until six months but not between six months and two years postoperatively[155]. Several studies consistently reported that the mean long-term patient-reported outcomes measured with validated scoring systems in patients who have suffered pilon fractures are significantly lower than those of age-matched healthy controls[158,164].

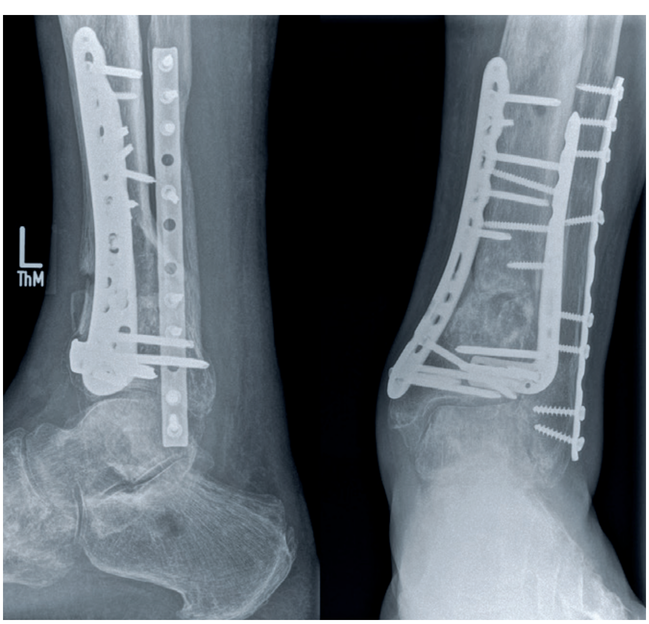

Figure 9. Standing radiographs at one year demonstrate consolidation of the fractures without loss of reduction or signs of early post-traumatic arthritis (same patient as in Figures 2-7).

Figure 10. (A) Clinical aspect and (B) ankle range of motion at one year. Note that the patient has a fused ankle on the right side from a previous accident (same patient as in Figures 2-8).

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Special Article

Pediatric hallux valgus

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Abstract

Pediatric hallux valgus is a common condition that may present with various symptoms. In children with underlying neuromuscular diagnoses, treatment strategies can be fairly straightforward: if the deformity is painful and challenging to manage due to hygienic or shoewear problems, first metatarsophalangeal joint arthrodesis is indicated as a safe, reliable, and single surgical procedure. In ambulatory healthy children, skeletal maturity status and the remaining growth should be strongly considered. Surgical treatment options are indicated for patients with recalcitrant pain and symptoms despite a dedicated effort towards activity and shoewear modifications. If possible, surgery should be delayed until the complete closure of the physes. Various procedures exist to correct hallux valgus, and surgeons should critically analyze and select the most appropriate option. Recurrence may be a significant risk, particularly in the pediatric and adolescent population.

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

Keywords: Pediatric; Hallux valgus; Bunion.

Introduction

Pediatric hallux valgus is a relatively common condition, with a reported incidence of up to 36%[1]. Various terminology describes its presentation: juvenile or adolescent bunion, metatarsus primus varus, and metatarsus primus adductus. The etiology of pediatric hallux valgus is unclear; however, several features have been identified as potentially predisposing factors: a positive family history, female sex, pes planus, a relatively long first metatarsal, constrictive footwear, and metatarsus primus varus[2,3]. Patients may complain of a painful, erythematous bunion, dissatisfactory cosmetic deformity, and difficulty or pain with appropriate footwear. Treatment strategies for pediatric hallux valgus mirror those available for their adult counterparts. Non-operative management is initially recommended, starting with footwear modifications or orthotics. However, the literature suggests that these non-operative measures have a limited role in preventing the progression of the deformity[4,5]. Surgical intervention is considered after failed conservative management, with numerous surgical options described in the hallux valgus correction. In the pediatric and adolescent populations, the risk of recurrence after deformity correction is high[6]. Nonetheless, outcomes are generally favorable.

Anatomy

One of the most important functions of the great toe is stabilizing the medial longitudinal arch. When the first metatarsophalangeal (MTP) joint is extended (during the third rocker in the stance phase of the gait), the sesamoids, connected to the base of the proximal phalanx, cause tension on the plantar fascia and improve the forefoot surface area of contact with the ground[2,7]. This biomechanic sequence is called the "windlass" mechanism and is impaired when the great toe has a valgus alignment.

The hallux valgus deformity occurs in steps, either sequentially or in parallel. First, the medial supporting structures of the first MTP joint (medial sesamoid and collateral ligaments) fail. Next, the metatarsal head shifts medially, slipping out of the sesamoid apparatus. The proximal phalanx then moves into a valgus position as it is tethered by the sesamoids, the deep transverse ligament, and the adductor hallucis tendon. Then, the metatarsal head

Study performed at the Beth Israel Deaconess Medical Center, Boston, MA, United States.

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rests on the medial sesamoid, causing cartilage erosion. This triggers a bursal thickening over the medial eminence. After that, the extensor and flexor hallucis longus tendons appear to bowstring laterally, further increasing the valgus displacement of the proximal phalanx. The metatarsal head pronates after dropping off the sesamoid apparatus, making the flexor tendons potent great toe abductors and worsening the valgus deformity of the great toe (Figure 1). The weaker dorsal MTP joint capsule rotates medially with pronation, thereby losing its inherent stability. Finally, the metatarsal head elevation and medial motion transfer plantar pressure laterally[8].

In the skeletally immature child, consideration for open physes should be emphasized. The great toe distal and proximal phalanx physes are expected to close at age 17-18. The first metatarsal physis is expected to close at the same age. Note that the first metatarsal physis is anatomically proximal to the long axis of the metatarsal, whereas the second through fifth metatarsal physis is located distally (Figure 2 A and B).

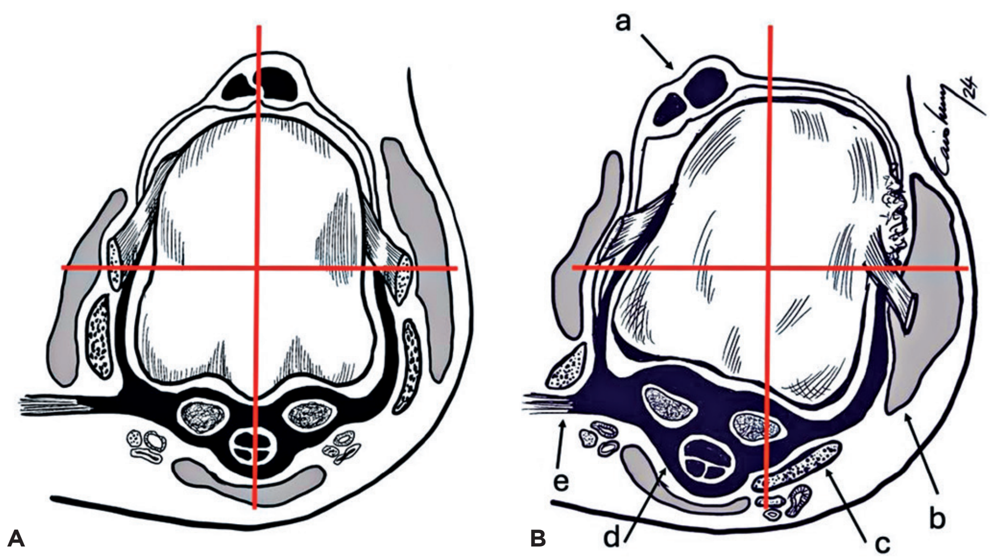


Figure 1. (A) Flexor and extensor tendons on the first metatarsal head at the median plane. (B) Flexor and Extensor tendons shifted laterally, becoming deforming forces and bringing the great toe to valgus position when activated.

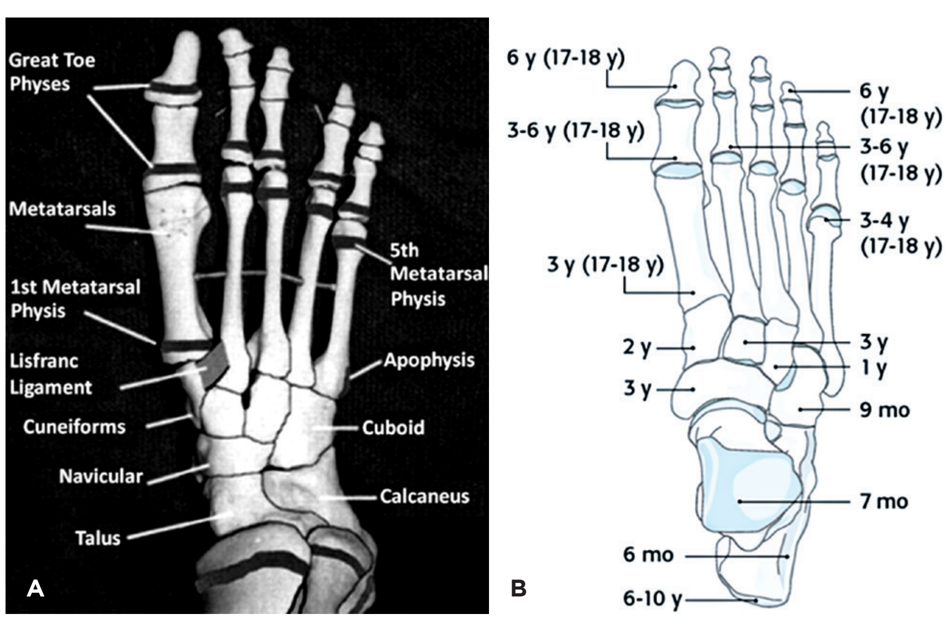


Figure 2. (A) The figure shows where the growth plates are in the bones. (B) Estimate when the growth plates close completely.

Pathophysiology

The pathogenesis of pediatric hallux valgus is complex. Over 80% of patients are female, and approximately half of these patients present before the age of 10. Maternal transmission may be common, particularly in young patients[9].

Various theories on the anatomic etiology of pediatric hallux valgus have been suggested. Metatarsus primus varus, which may be detected in infancy, is commonly suggested as an etiologic basis. However, other anatomic variations, such as an oblique first metatarsal-cuneiform articulation, a laterally deviated distal metatarsal articular angle, or a flat or conical first MTP joint have been suggested as possible causes or associations[10,11].

Additionally, flexible pes planus and ligamentous laxity have been associated with hallux valgus; however, given its common presentation, the relationship between these deformities has not been confirmed. Hallux interphalangeus and metatarsus adductus are commonly associated with hallux valgus[9].

Hallux valgus in patients with neuromuscular pathologies results from malalignment in various foot and ankle segments and is not a congenital finding. The imbalance between intrinsic and extrinsic muscles and the abnormal biomechanics on the forefoot, especially in the third phase of the stance, will cause deformity with time[9]. Initially, the abductor halluces muscle is hyperactive, bringing the toe to valgus deformity, starting this cascade of events affecting other anatomic structures of the forefoot, particularly on the first ray. In patients with flatfoot deformity because of cerebral palsy, the hyperactivity of the peroneus longus can negatively affect the toe alignment. Since the oblique head of the abductor halluces muscles originates from the peroneal longus tendon, the great toe will have forces applied to its lateral aspect, bringing the toe to the valgus position[12-14]. Neuromuscular pathologies can also lead to arch collapse, pronating the forefoot and the first metatarsal[2-15], changing the axis of the great toe flexion/extension movement, also resulting in apparent great toe valgus deformity[11]

Physical examination

A thorough examination is imperative for any pediatric or adolescent patient who presents with hallux valgus. The first determination should be whether the deformity is rigid or flexible. If passively correctable, the examiner should note the foot position and width while the great toe is in the corrected position. A concomitant flatfoot deformity should be noted, and whether it is rigid or flexible. Calluses should be assessed—a medial callus suggests poor shoe fitting, whereas a plantar callus suggests transfer metatarsalgia. Other associated deformities should be recognized, including hallux interphalangeus and metatarsus adductus. As flatfoot develops, the peroneal longus, instead of coming from lower down (bottom of the cuboid) to plantarflex the first metatarsal, makes a loop on the plantar cuboid and runs parallel to the floor. As it inserts on the plantar aspect of the first metatarsal base, in addition to plantarflexing the first metatarsal, it additionally creates pronation.

The range of motion of the first interphalangeal and MTP should be documented. The stability of the first tarsometatarsal (TMT) joint should be assessed and documented.

Patients in this age population frequently only see one orthopedic provider; a thorough examination of the bilateral lower extremities should be performed. Any additional abnormalities, such as leg length discrepancy, genu varum, genu valgum, and ankle and hindfoot alignment, should be noted and addressed as indicated. Gastrocnemius tightness, tested with the Silfverskiold test, has been reported to contribute to the pathogenesis of juvenile hallux valgus and thus should be tested[16].

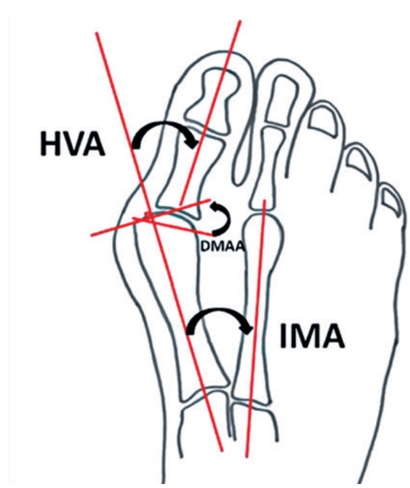
In patients with cerebral palsy or similar neuromuscular syndromes, a key presentation feature is when the great toe is over- or underlapping the second toe, which may cause pain, poor hygiene, difficulty with shoe or orthotic wear, and disruption of gait.

Imaging

Complete radiographs of the bilateral feet are necessary for evaluation and planning. Formal weight-bearing anteroposterior and lateral views and non-weight-bearing oblique views are imperative. These images allow for accurate measurement of the hallux valgus angle, the intermetatarsal angle (IMA), the inclination of the metatarsal-cuneiform articulation, and the distal metatarsal articular angle.

Mild deformity is defined by IMA greater than 9º and hallux valgus angles (HVA) greater than 15º. Moderate deformities are IMA between 12 and 16º and HVA between 20 and 40º. Severe deformities include patients with IMA greater than 16º and HVA greater than 40º.

The distal metaphyseal articular angle (DMAA) should also be evaluated since values above 11º should be corrected, usually with biplanar distal osteotomies (Figure 3).



HVA: Hallux valgus angle. IMA: Intermetatarsal angle. DMAA: Distal metatarsal articular angle.

Figure 3. Radiographic parameters

Several notable details on radiographs should be appreciated. Detailed inspection should assess the presence of an articular facet at the TMT joint between the first and second metatarsals, which may restrict deformity correction at that level, such as in the case of TMT arthrodesis. The unity of the first MTP joint should be appreciated, as congruent joints are considered stable and amenable for motion-preserving deformity correction, while incongruent joints may suggest degenerative changes or instability, for which arthrodesis may be more strongly considered.

Open physes should be noted for several reasons. Surgical techniques that involve growth modulation depend on the presence of an open physis(6). A high recurrence rate has been reported in patients with growth remaining(17,18). As such, postponing surgical correction by osteotomy and/or soft tissue balancing until skeletal maturity has been achieved has been advocated by some surgeons to minimize the risk of recurrence(9,18).

If any concern for leg length discrepancy or alignment is suggested by physical examination, a standing scanography, including bilateral legs from hips to ankles, should be obtained to investigate further.

Advanced imaging, such as computed tomography (CT) or magnetic resonance imaging (MRI), is rarely indicated. However, recent studies have shown some efficacy in weight-bearing CT in evaluating the pronation of the first metatarsal and better assessment of the DMAA(16,19).

Treatment

Conservative management

In the growing child with open physes, conservative treatment is the gold standard. The use of orthoses and shoewear modifications should be recommended to allow time for completion of growth and prevent overcorrection or recurrence. Additionally, non-operative treatment provides for the maturation of soft tissues and the natural improvement of ligamentous laxity, which may result in the resolution of any associated flexible pes planus. By allowing the patient to progress to skeletal maturity before surgery, any risk for secondary sequelae due to premature physeal closure is mitigated.

In cases where pediatric hallux valgus deformity is asymptomatic, no intervention is required. Patients and their parents should be advised to monitor for any onset of symptoms and deformity progression. If symptoms arise, the first recommended treatment is activity and shoewear modification.

Orthosis has been a mainstay in the treatment of flexible pes planus and is often helpful for hallux valgus with concomitant pes planus. Stabilization of the flatfoot deformity may improve the pain and symptoms of the great toe(3,4).

Bracing has not been shown to prevent deformity progression. In a study by Kilmartin et al.(4), children who presented with unilateral hallux valgus eventually developed hallux valgus on the initially unaffected side despite using bilateral braces(4).

Groiso(3) published a study on the efficacy of night-time thermoplastic splinting and passive and active exercises. In this study, the authors found improvement in the MTP joint angle and/or the IMA in approximately half of the feet. No recurrences were detected among patients who demonstrated improvement. It should be noted that this study has not been replicated and serves as a historical source advocating for bracing. Nery et al.(5) published their series where IMA and HVA were measured before and after the same customized orthoses were used at night. Besides the fact that 44% of the patients had to be excluded due to discomfort using the orthosis and giving up on the treatment, they found no difference in the radiographs of patients who did use the orthosis for a long time(5).

In the neuromuscular child, the treatment objective is to achieve hygiene and reduce pain, rather than cosmesis and conventional footwear. As such, conservative management goals focus on the ability to provide hygiene to the first web space and to monitor for any pain responses due to the hallux valgus deformity.

Surgical management

The primary indication for surgical deformity correction is pain. Symptom severity may not reflect the degree of clinical or radiographic deformity, and as such, the degree of deformity in the absence of symptoms should not be used as an indication for surgery.

Over 130 different procedures have been described for the management of this condition. A description of each technique is outside the scope of this review paper. Generally, procedures can be classified into four major categories: soft-tissue procedures, proximal metatarsal osteotomy, distal metatarsal osteotomy, and combined techniques.

In the skeletally immature child, surgical treatment options are limited, as damage and premature physeal closure may lead to secondary deformity and poor outcomes. As the metatarsal physis of the first metatarsal is located proximally, proximal metatarsal osteotomies are generally contraindicated. Distal metatarsal osteotomies may be more favored if surgery is indicated; however, its correction power may be limited since shifting the head of the first metatarsal more than 50% of its width is generally avoided. If significant growth remains, the first metatarsal with metatarsus primus varus will continue to grow with pathologic alignment, leading to poor long-term outcomes. Similarly, given the high recurrence rate associated with soft tissue-only procedures, these techniques are not recommended in patients with significant growth remaining. Thus, in the skeletally immature child, alternative techniques should be considered.

Davids et al.(6) reported positive results in a small patient series utilizing a lateral hemiepiphysiodesis technique. By arresting the lateral aspect of the physis using a small drill and curette, the remaining active area of the first metatarsal physis is allowed to continue longitudinal growth, resulting in angular correction of the IMA (Figure 4 A, B, and C). The authors suggest this procedure in symptomatic children with pediatric hallux valgus and two or more years of growth remaining who have failed a trial of shoewear modification and/or have a documented progression of deformity over time[6].

In skeletally mature patients, procedures may be used to address hallux valgus deformity in adults. The degree of deformity measured on radiographs should be utilized to select the appropriate surgical procedure. For example, a Chevron osteotomy or a modified McBride procedure is sufficient to treat mild deformities. A distal soft tissue correction and a proximal osteotomy may be indicated for deformities with MTP subluxation, and proximal and distal osteotomies should be considered for severe deformities with increased DMAA. This algorithm, suggested by Coughlin, offered good or excellent results in 92% of the reported cases[9].

Simple bunionectomy has fallen out of favor, as recurrence of symptoms and progression of deformity have shifted management strategies. While bunionectomy may still be performed to address localized pain due to pressure over the medial eminence, patients and families must understand that the procedure alone will not address the underlying pathoanatomy.

The modified McBride, a combination of bunionectomy and extensive soft-tissue procedures, including adductor hallucis release or transfer, lateral capsular release, and medial capsular plication, has been reported with success. Especially in younger patients, a notable complication from extensive lateral release is secondary hallux varus[20,21].

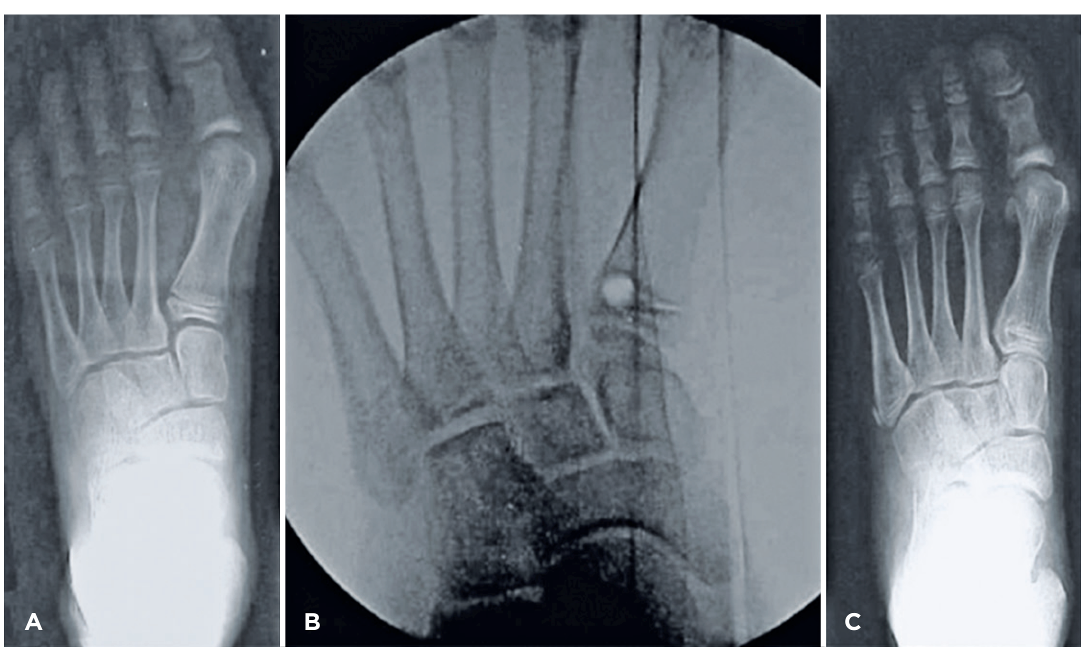
Various distal metatarsal osteotomies have been reported, with improved results associated with internal fixation or stable osteotomy configuration (i.e., Chevron osteotomy) [22,23]. Inherently, distal osteotomies create some metatarsal shortening and may be especially useful in patients with a long first metatarsal. Surgeons should be aware that transfer metatarsalgia may result if the second metatarsal becomes relatively too long after shortening of the first metatarsal.

In cases where the DMAA is increased, techniques such as biplanar Chevron or Scarf osteotomy may produce better correction and maintain metatarsal length if desired. Rotational correction should be achieved to fully correct the DMAA within the normal range (Figure 5 A and B).

Particularly in children and adolescents with ligamentous laxity, the surgeon must assess the stability of the TMT joint. If there is evidence of instability or hypermobility of the first TMT joint, distal procedures alone should be avoided, and TMT arthrodesis (Lapidus procedure) should be considered. It should be noted that the first TMT instability remains controversial, as objective measurement for instability is limited, particularly regarding axial plane instability[24].

This procedure allows both correction of the deformity and improvement of the IMA, as well as eliminating joint instability. Given the proximity of the physis and its proximal location along the first metatarsal, this procedure should be reserved for skeletally mature patients.

Arthrodesis of the first MTP joint is usually reserved for patients with significant degenerative changes, an extremely rare finding in pediatric patients. One important exception would be patients with neuromuscular pathologies who



Figures 4. (A) Preoperative radiographa of a juvenile hallux valgus with abnormal intermetatarsal angle. (B) Intraoperative fluoroscopy of lateral physes drilling to perform hemiepiphysiodesis. (C) Long-term postoperative with gradual intermetatarsal angle correction.

need procedures to facilitate hygiene or avoid skin ulceration between the great and second toe.

As minimally invasive techniques have gained popularity, choosing an osteotomy at the correct level should rely on the earlier principles[25]. Over the last two decades, from the first generation, which had used poor fixation, to the current fourth generation, which uses specific screws designed for minimally invasive procedures, outcomes have shown to be consistently better. Additional benefits are using minimally invasive techniques: immediate weight-bearing status, improved cosmesis, a notable decrease in immediate postoperative pain, and possibly less stiffness compared with open procedures as the osteotomy is an extra-articular, therefore avoiding capsulotomies[26] (Figure 6 A and B).

In syndromic patients with cerebral palsy or other neuromuscular disease, the main aim of treatment is to provide a painless, stable, comfortable position of the great toe. This is best achieved with a single safe and reliable surgery, the first MTP joint arthrodesis. This option offers the greatest degree of correction and best outcomes compared to other techniques[27]. Given the inherent muscle imbalance due to spasticity or paresis, soft tissue or joint realignment procedures are not recommended.

Outcomes

Outcomes after surgical treatment of pediatric hallux valgus are generally favorable. Recurrence of deformity is a risk for any hallux valgus procedure at any age and is especially a concern in younger patients.

In one long-term study, Schwillate et al.[20] report on the outcomes of 17 feet after the modified McBride procedure. Outcomes were good in 10, satisfactory in 2, and dissatisfying in 5, with a mean of 14-year follow-up[20]. Recurrence rates after distal metatarsal osteotomies such as the Mitchell osteotomy have been reported to be up to 61% in one study by Ball and Sullivan.[28]. However, in a study by Geissele and Stanton[1], a successful correction was reported up to 95%[1].

The Scarf osteotomy has demonstrated positive results. John et al.[29] reported on seven patients with a mean age of 14 years, with only one recurrence after 14 years[29]. Farrar et al. reported that 39 feet were submitted to Scarf osteotomy at a mean age of 14, and 93% of the results were satisfactory at 3 years[30]. One study cautioned against Scarf osteotomy, as they found a high recurrence rate in a series of 19 feet with a mean age of 14[31]. The Lapidus procedure has been reported to have favorable outcomes. In a series of 30 feet, good or excellent results were reported in 90% (27 feet) by Grace et al.[32].

Figure 5. (A) Preoperative juvenile hallux valgus with abnormal intermetatarsal angle and distal metaphyseal articular angle. (B) Intermetatarsal angle and distal metaphyseal articular angle correction after biplanar Chevron osteotomy.

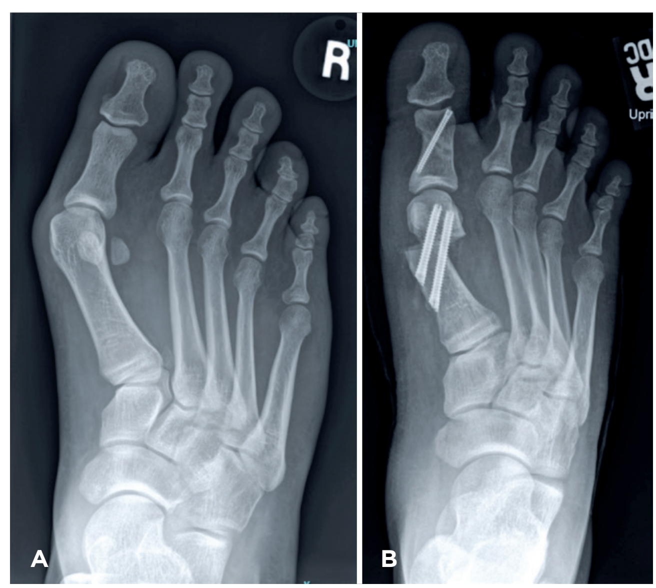


Figure 6. (A) Preoperative juvenile hallux valgus. (B) Correction with minimally invasive technique (Distal first metatarsal Osteotomy + Akin)

Authors' contributions: Each author contributed individually and significantly to the development of this article: DSL, and CPM, and FCR *Conceived and planned the activities that led to the study, data collection, wrote the article, approved the final version. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Special Article

Supramalleolar osteotomies: what and when?

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Abstract

Supramalleolar osteotomy is an option in treating ankle osteoarthritis, being the main indication in cases with partial joint involvement and preserving at least 50% of the joint surface. With an adequate understanding of the pathology and a proper surgical indication for joint realignment, most patients do not need conversion to arthrodesis or ankle arthroplasty with short or medium follow-up.

Level of evidence V; Expert opinion.

Keywords: Ankle; Osteoarthritis; Osteotomy; Joint.

Introduction

Ankle osteoarthritis (OA) affects 1% of the population worldwide[1]. This condition commonly affects individuals 12 to 15 years younger than individuals with hip or knee OA[2]. This is because most ankle OA is post-traumatic, unlike hip and knee OA, which are mostly primary of these joints[1,3].

Surgical treatment of ankle OA is divided into two categories: non-joint-preserving surgeries and joint-preserving surgeries. The non-joint-preserving surgeries are ankle arthrodesis and arthroplasty, which are widely used, but with potential complications. Due to the blockage of the ankle joint, ankle arthrodesis can lead to OA in adjacent joints[4]. Ankle arthroplasty has a survival rate between 80% and 90% in 10 years, thus, depending on the patient's age, revision surgery is required.

Supramalleolar osteotomy is a joint-preserving surgery that has its main indication in partial OA of the joint, that is, in case of asymmetric OA in varus or valgus ankle, preserving at least 50% of the joint surface[5] (Figure 1). The goal of supramalleolar osteotomy is to realign the tibia with the talus in the coronal and sagittal planes, decreasing pressure in the compromised joint area and partially transferring this pressure to the most preserved area. Approximately two-thirds of ankle OA are asymmetrical, with greater medial or lateral joint involvement[6].

Deformity type and location

Asymmetric ankle OA can be classified as a varus or valgus, congruent or incongruent deformity. In congruent deformity, there is a slope of 4° or less between the proximal articular surface of the talus and the distal articular surface of the tibia. In incongruent deformity, there is a slope greater than 4° between the proximal articular surface of the talus and the distal articular surface of the tibia; this slope is called talar tilt (TT)[7,8] (Figure 2).

In most cases of asymmetric ankle deformity, the deformity apex occurs at the ankle level or near the ankle. Especially in wedge osteotomies as osteotomy is not performed at the apex of the deformity, a translation of the distal fragment occurs. Wedge osteotomies to correct valgus ankle led to the medialization of the distal fragment (ankle), while to correct varus ankle, it leads to the lateralization of the distal fragment (ankle). This translation of the distal fragment does not occur in dome osteotomy (Figures 3 and 4). In a valgus ankle, medializing the distal fragment results in excessive load on the lateral side of the ankle; thus, a lateral translation of the distal fragment is necessary. Similarly, for varus ankle correction, the lateral translation of the distal fragment leads to medial overload in the ankle, so the medial translation of the distal fragment must be included. This corrective translation should be performed, especially in major deformities[9].

Study performed at the Hospital Mãe de Deus, Porto Alegre, RS, Brazil.

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Supramalleolar dome osteotomy is an alternative to wedge osteotomy and should be indicated, especially in OA where the deformity is metaphyseal, which occurs mainly in congruent OA.

Osteoarthritis severity classification

The Takakura classification[10] is used to grade OA and define the surgical procedure required (Table 1).

Grade 4 involves the entire ankle joint; therefore, supramalleolar osteotomy is a contraindication. The exception would be cases where there is a broader planning, for example, performing a supramalleolar osteotomy to improve ankle alignment and later perform an ankle arthroplasty. In grade 3b, supramalleolar osteotomy may be indicated; however, due to the degree of joint involvement, results are worse than in grades 1, 2, and 3a[11,12].

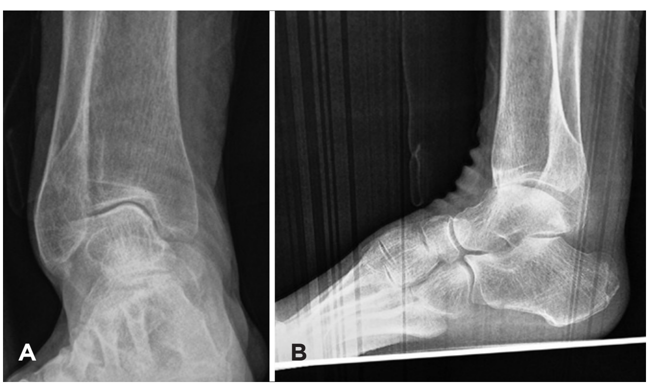

Figure 1. Weight-bearing (A) anteroposterior and (B) lateral ankle radiographs. Asymmetric ankle OA with varus deformity of the distal articular surface of the tibia with partial ankle joint preservation.

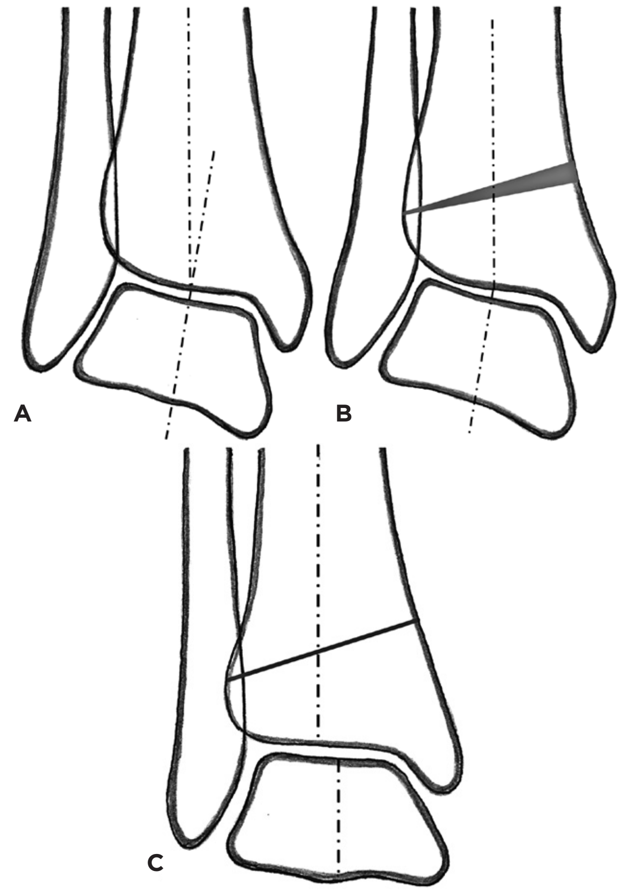

Figura 3. (A) Congruent valgus deformity with the apex at ankle level; (B) supramalleolar osteotomy with medial closing wedge proximal to the deformity apex; (C) correction of the alignment of the distal articular surface of the tibia with medialization of the center of the talus.

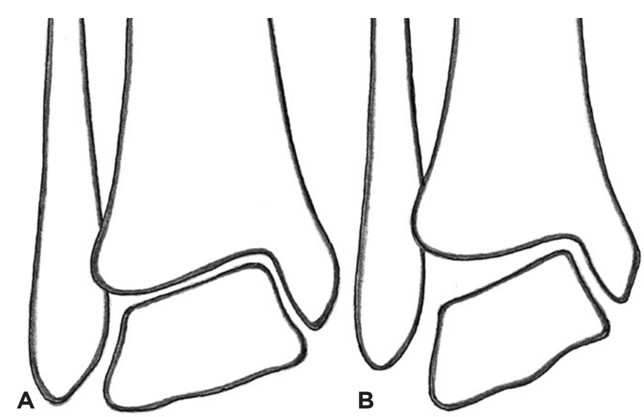

Figure 2. Shows the two asymmetric ankle OA types: (A) congruent, with the talus parallel to the distal articular surface of the tibia; and (B) incongruent, with the talus inclined to the distal articular surface of the tibia.

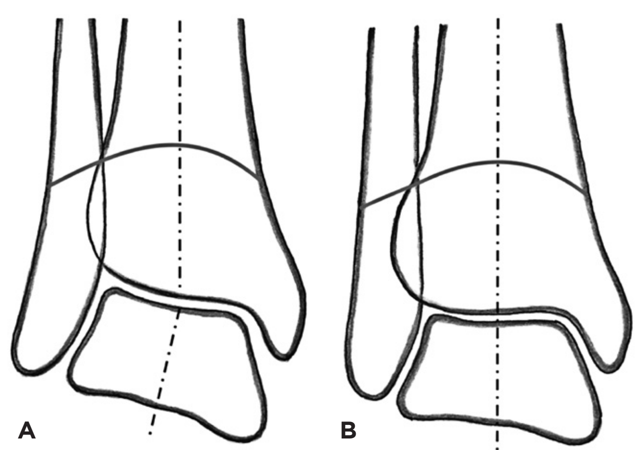

Figure 4. (A) Dome osteotomy of the distal tibia; (B) with the dome osteotomy, the center of the talus was aligned with the mechanical axis of the tibia.

Preoperative clinical evaluation

Clinical alignment of the lower limbs is analyzed. Patients with varus ankle may have calcaneal valgus alignment, and the correction may lead to excessive calcaneal valgus with sub fibular impingement. Passive ankle extension is evaluated to identify gastrocnemius contracture and assess ankle medial and lateral ligament stability, inversion force of the posterior tibial tendon, and the eversion force of the peroneal brevis and longus tendons.

Preoperative radiographic evaluation

The radiographic evaluation consists of a panoramic radiograph of the lower limbs, weight-bearing anteroposterior (AP) and lateral radiographs of the ankle, and weight-bearing AP and lateral radiographs of the foot. The medial distal tibial angle (TAS) consists of the angle formed between the line of the anatomical axis of the tibia and the line joining the most medial point to the most lateral point of the distal articular surface of the tibia on the AP radiograph of the ankle, with a normal value of 86° to 89°[13,14]. This angle shows if the deformity is above the ankle. The tibiotalar surface angle (TTS) consists of the angle formed between the line of the anatomical axis of the tibia and the line joining the most medial point to the most lateral point of the proximal articular surface of the talus on the AP radiograph of the ankle; this angle shows the alignment of the talus with the axis of the tibia. The difference between TAS and TTS is indicated as TT, which shows the inclination degree of the talus considering the distal articular surface of the tibia. As previously mentioned, a TT equal to or less than 4° characterizes a congruent joint, and a TT greater than 4° characterizes an incongruent joint. In lateral radiographs with ankle load, the tibial lateral surface angle (TLS) is evaluated, which is the angle between the line of the anatomical axis of the tibia and the line joining the most posterior point to the most anterior point of the distal articular surface of the tibia, normally being 83° (± 2°). The sagittal talar translation (STT) is also evaluated, which is the ratio between the distance from the middle of the talar dome, assessed with a circle fitting in the talar dome, to the tibial axis and the length of the distal tibial articular surface on the lateral view[15]. The Saltzman incidence shows the alignment of the hindfoot through the moment arm of the calcaneus on hindfoot view. A horizontal distance between the tibial axis (weight-bearing axis of the leg) and the most inferior point of the calcaneus was defined as the moment arm[16] (Figure 5).

In addition to radiographic evaluation, MRI or CT scans may be necessary. The first is indicated mainly in early cases of OA, where edema in the subchondral bone may be the only sign

Table 1. Takakura's classification for ankle osteoarthritis and varus deformity[10]

Stage	Radiographic findings
1	No joint space decrease, subchondral sclerosis, and osteophyte formation
2	Reduced medial joint space
3a	Obliteration of the space, with contact of the subchondral bone of the medial articular surface of the talus with the medial malleolus (medial leak only)
3b	Worsening of the joint space obliteration, contact of the subchondral bone of the medial talar dome with the medial tibial plafond
4	Complete obliteration, with full contact of the dorsal subchondral bone of the talus with the subchondral bone of the tibial plafond

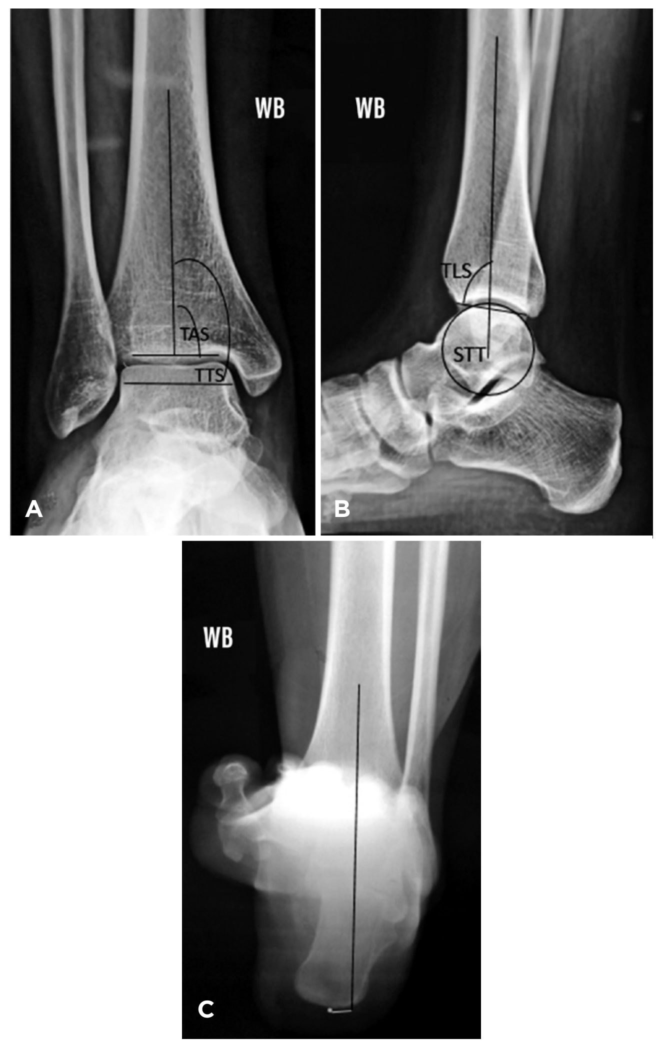

Figure 5. Radiographic evaluation of the ankle. (A) AP weight-bearing plain radiograph of the ankle evaluating the medial distal tibial surface angle and the tibiotalar surface angle; (B) Lateral weight-bearing plain radiograph of the ankle with evaluation of the tibial lateral surface angle and sagittal talar translation; (C) Saltzman's hindfoot weight-bearing with moment arm evaluation of the calcaneus.

indicative of joint impairment, while the second is indicated in most cases, with three-dimensional reconstruction being very useful for identifying osteophytes that need to be resected during surgical intervention.

Subtalar joint compensatory capacity

Poor hindfoot alignment (inframalleolar deformity) results from alterations in the alignment or shape of the calcaneus, leading to changes in the subtalar joint orientation. Takakura et al.[10] speculated that the subtalar joint has a compensatory function preventing OA progression: in ankle varus deformity, the subtalar joint would assume a valgus orientation, with OA progression only occurring when there is a loss of this compensatory function[10]. A subsequent clinical study confirmed these findings[17]. Using radiographs, Hayashi et al.[18] demonstrated there was a more valgus subtalar joint in the intermediate stages of OA in varus ankle, while in the more advanced stages, the subtalar joint assumed a neutral or varus position, that is, there was a loss of subtalar compensatory power[18].

There is an anatomical variability in the subtalar joint, which leads to differences in its capacity to accommodate and adapt. A study showed that 88% of the population have a concave posterior facet of the subtalar joint, and 12% have a flat posterior facet. Individuals with a flat posterior facet have decreased mobility of this joint in the coronal plane, with less compensating power for varus or valgus ankle[19]. A study showed that patients with OA in varus ankle have a varus inclination of the subtalar joint posterior facet, and patients with OA in valgus ankle have a valgus inclination of the subtalar joint posterior facet[15]. Patients with OA of the subtalar joint also have a decreased compensatory capacity in the subtalar joint for ankle varus or valgus deformities. Therefore, the subtalar joint behavior in asymmetric ankle OA is complex and varies.

The subtalar joint ability to compensate for deformity in cases of asymmetric ankle OA can result in paradoxical deformities. For instance, this may lead to ankle varus deformity while the calcaneus remains neutral or valgus.

Surgical indication

Varus ankle treatment

The procedure starts with an open joint debridement but can be performed by arthroscopy in certain cases. The objective is to perform the resection of bone spurs and remove intra-articular free bodies. Avoiding excessive anterior bone resections in the tibia is important, as this can lead to instability and anterior migration of the talus.

In the coronal plane, as previously mentioned, TAS has an anatomical inclination of 86° to 89°. The type of supramalleolar osteotomy to be performed depends on where the deformity apex is, the soft tissue conditions, and whether the OA is congruent or incongruent. Congruent deformities are preferably corrected with dome osteotomy, and incongruent osteotomies are corrected with wedge osteotomy, which may be a lateral closing wedge or a medial opening wedge, depending on the case[20] (Figure 6). If patient has medial cartilage loss, the goal of the osteotomy is to obtain 2º to 4º valgus at the TAS, that is, a slight valgus at the end of the correction. In cases of large incongruent deformity, equal to or greater than 15°, due to the large amount of bone to be grafted or resected in a wedge, a dome osteotomy can be considered[5].

The medial opening wedge osteotomy allows a gradual varus correction until the appropriate degree is achieved in the coronal plane; in addition, if necessary, an anterior opening wedge can be performed aiming at the correction in the sagittal plane, by moving the anatomical axis of the tibia closer to the center of rotation of the talus. This correction in the sagittal plane is necessary for patients with anterior translation of the talus in relation to the tibia. The decision to perform a simultaneous fibular osteotomy is typically made intraoperatively and is based on the degree of deformity present. In our experience, fibula osteotomy is performed in most cases. Hintermann et al.[5] generally perform fibular osteotomy in deformities greater than 10°[5].

The lateral closing wedge osteotomy has the advantage of not requiring a bone graft. Theoretically, it provides greater stability and reduces pressure within the ankle joint due to the subtraction of bone. It usually requires fibular osteotomy; otherwise, the fibula can get long and have a subfibular impact. Disadvantages include the increased difficulty in gradually correcting the deformity and the requirement for a biplanar wedge when correction is needed in both the coronal and sagittal planes (Figure 7).

In some cases, a medial impaction of the distal articular surface of the tibia can occur, and if greater than 5°, an intra-articular osteotomy called "plafondplasty" can be performed to restore articular congruence[21]. A Kirshner wire is inserted into the apex of the intra-articular deformity, and an additional wedge osteotomy is performed using bone graft and fixation, usually performed with an anterior plate in the tibia.

In most cases of supramalleolar osteotomy, fixation is performed with a plate in the tibia, and a compression screw can be added to the osteotomy. In the fibula, the fixation is performed with a plate. In complex cases, fixation with an external fixator and gradual deformity correction can be used, especially with fixators that allow three-dimensional correction.

Valgus ankle treatment

Like in the varus ankle correction, surgery starts with a joint debridement, usually open, and arthroscopy in certain cases.

In cases of congruent articulation, correction is preferably made with dome osteotomy; in cases of incongruent articulation, medial closing wedge (majority of cases) or lateral opening wedge (minority of cases) is preferably performed. The medial closing wedge osteotomy is performed to obtain 2º to 4º varus at the tibial joint surface. The lateral cortex of the distal tibia is more resistant than

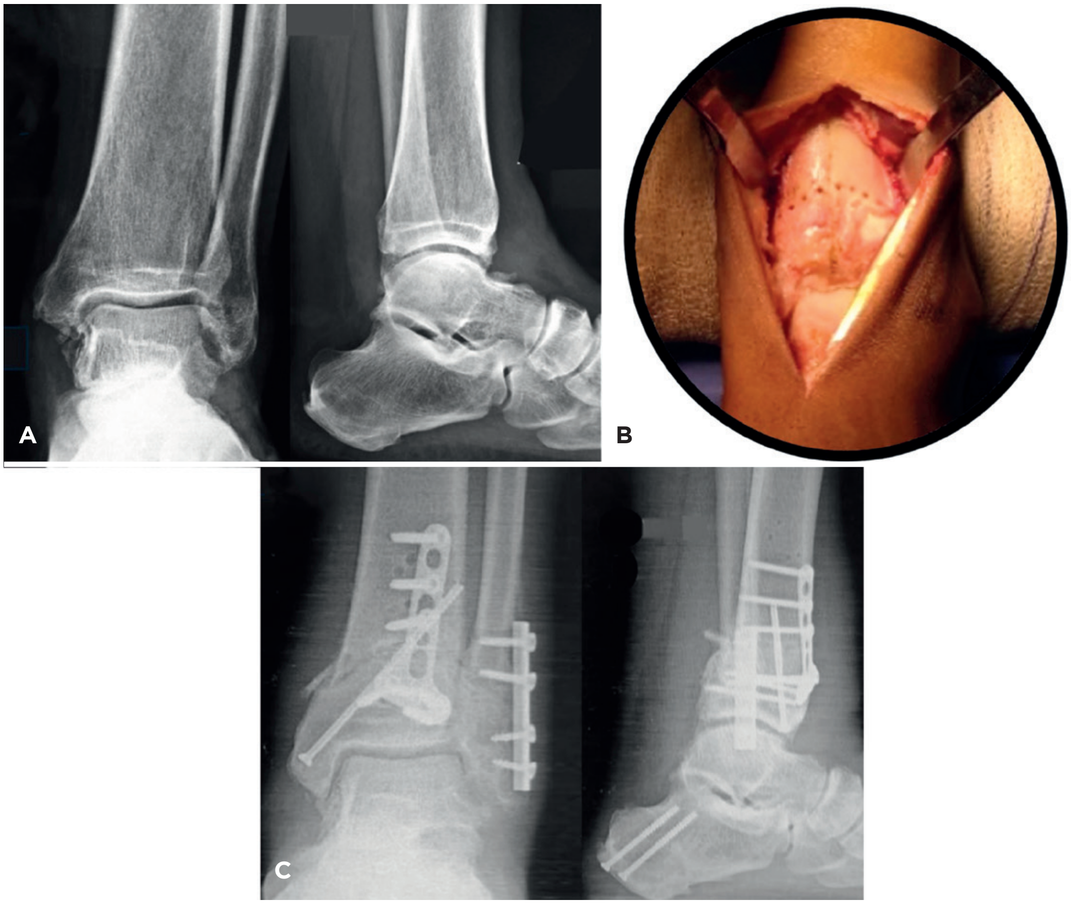

Figure 6. Male patient, 40 years old, with two previous medial ankle debridement surgeries by bone impact. Distal tibial dome osteotomy, fibular osteotomy, and calcaneus valgus osteotomy were performed. (A) Preoperative radiographs; (B) intraoperative image of the distal tibial dome osteotomy; (C) postoperative radiographs.

Figure 7. Lateral tibial closing wedge and fibular osteotomy to treat asymmetric varus ankle OA. (A) AP and (B) Lateral pre-operative radiographs; (C) AP and (D) lateral post-operative radiographs.

the medial cortex, thus, with the placement of an anterior or anteromedial plate, there is good stability and a low risk of instability in the synthesis. In performing dome osteotomy, it is always necessary to perform a fibular osteotomy. In the closing wedge osteotomy, if there is no adequate reduction of the talus with joint congruence, fibular osteotomy should be performed to rotate the fibula or, if necessary, lengthen the fibula[22] (Figure 8).

Lateral opening wedge osteotomy for valgus correction is reserved for cases with poor medial soft tissue quality or concerns about shortening caused by the closing wedge. Bone graft and fibular osteotomy are required. A disadvantage of lateral opening wedge osteotomy is that the medial cortex of the distal tibia is weaker than the lateral cortex, thus, even if the distal tibia is laterally fixed with a plate, a medial incision may be necessary to place a second plate medially aiming to minimize the risk of instability and reduction loss[5].

In cases of large incongruent deformity, deformities equal to or greater than 15°, due to the large amount of bone to be grafted or resected in a wedge, a dome osteotomy can be considered[5].

Fibular osteotomy

Biomechanical studies show the importance of maintaining or recovering joint congruence in supramalleolar osteotomy to achieve a more reliable pressure redistribution at the ankle[23,24]. Placement of the talus congruently at the ankle joint may require adjustment in fibula length[23,25]. Each case should be assessed individually, particularly in cases of congruent deformities. Beyond correcting the angulation of the distal articular surface of the tibia, it is crucial to evaluate the potential need for fibular shortening or lengthening based on preoperative radiographic assessments, typically compared with the contralateral ankle. Even when the fibula length is adequate in radiographic evaluation, osteotomy is necessary in many cases to allow the best reduction of the talus in the ankle (Figure 9).

In dome osteotomy, fibular osteotomy is always necessary. In wedge osteotomy, the decision to perform fibular osteotomy may be intraoperative if the isolated correction of the distal articular surface of the tibia is not enough to improve articular congruence. Intraoperatively, the parameters to be

Figure 8. Patient with asymmetric valgus OA submitted to medial closing wedge and fibular osteotomies. (A and B) Preoperative radiographs; (C) tomography showing epiphyseal lateral lesion; (D and E) postoperative radiographs.

evaluated are: 1) recovery of the medial clear space, that is, the relationship between the medial articular surface of the talus and the medial malleolus; 2) parallelism between the distal articular surface of the tibia and the talar dome; and 3) recovery of the normal length relationship between the lateral malleolus and the medial malleolus(26). Stufkens et al.(24), in a biomechanical study, report that failure to perform fibular osteotomy limits correction with supramalleolar osteotomy in the tibia(24).

Sagittal plane deformity

In the sagittal plane, procurvatum and retrocurvatum deformities should be considered in ankle OA correction with osteotomy. Procurvatum deformity is better tolerated than retrocurvatum deformity. In retrocurvatum deformity, there is an anterior translation of the talus, with consequent greater pressure peaks in the ankle joint, causing a greater joint damage. Procurvatum deformity can cause pain due to the impact of the anterior bone on the ankle joint, but it has a greater tendency to preserve the joint surface(20,27,28).

Associated procedures

In patients with varus ankle, varus maintenance due to an inframalleolar deformity may occur because of subtalar joint stiffness, posterior tibial tendon contracture, or calcaneal deformity(5). In the presence of varus stiffness of the subtalar joint, it is necessary to perform a subtalar arthrodesis. When varus persists after supramalleolar osteotomy, it is often necessary to release the deltoid ligament. In varus patients with decreased eversion force, an alternative is the transfer of the peroneal longus tendon to the peroneal brevis tendon, aiming to increase the eversion force. Calcaneus osteotomy may be necessary to correct the residual inframalleolar deformity, being performed with lateral wedge and lateral sliding of the tuberosity or only lateral sliding of the tuberosity. In patients with excessive plantar flexion of the first metatarsal, it may be necessary to perform dorsal closing wedge osteotomy at the base of the first metatarsal for dorsiflexion of this metatarsal. If there is an accentuation of the tilt of the talus with varus stress of the ankle, lateral ligament repair of the ankle can be performed, for example, by the Broström-Gould technique; however, according to Krause et al.(29), in a study with cavovarus feet and lateral ankle instability, osteotomies and tendon transfers were sufficient, without lateral ligament repair and without the occurrence of postoperative ankle instability(29).

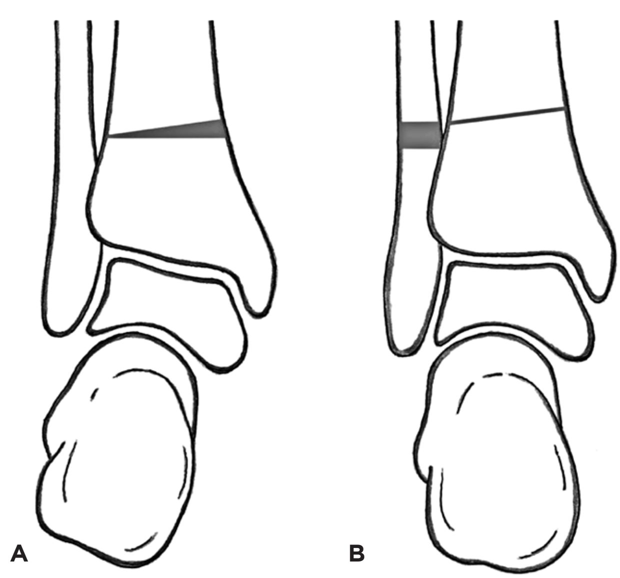

Figure 9. (A) Medial tibial closing-wedge osteotomy for valgus ankle deformity; (B) lengthening of the fibula is necessary to maintain the correct relationship between the medial and lateral malleolus.

In patients with valgus ankle, the inframalleolar deformity may be the result of peritalar instability, subtalar contracture, valgus malposition of the calcaneus, insufficiency of the medial soft-tissue structures (including the deltoid ligament and the posterior tibial tendon), or breakdown of the medial longitudinal arch(5). If the patient has a valgus hindfoot and subtalar arthrodesis is not required, a calcaneal varus osteotomy with medial sliding of the tuberosity can be performed. In specific cases, a medializing calcaneal osteotomy may be required combined with subtalar arthrodesis. The need for deltoid ligament reconstruction should be carefully assessed. If required, stabilization of the medial column can be addressed, for example, by performing arthrodesis of the first metatarsocuneiform joint. This procedure may involve using a dorsal-based bone graft to achieve stabilization and maintain appropriate flexion of the first metatarsal. Tendon balance should be evaluated and, if necessary, the flexor digitorum longus tendon can be transferred to the navicular to improve inversion, while the peroneal brevis tendon can be transferred to the peroneal longus tendon to decrease the eversion force of the hindfoot and improve plantar flexion of the first metatarsal.

Passive ankle dorsiflexion should be assessed during physical examination in varus or valgus deformity cases. If a limitation is identified, it is crucial to determine whether the gastrocnemius or the calcaneal tendon causes the restriction. This evaluation guides the appropriate surgical intervention intending to improve ankle dorsiflexion.

Complications

Loss of correction can occur due to failure in fixation, for example, by excessive early loading or by not identifying associated pathologies, such as ligament instability, neuromuscular pathologies, or inframalleolar deformities. Delay of consolidation or pseudarthrosis may occur due to insufficient fixation or failure of fixation. Overcorrection or undercorrection can result from errors in planning, improper surgical execution, or loss of correction during the postoperative period[30]. In case of deformities in the coronal and sagittal planes, both must be corrected; otherwise, pain may persist. This is particularly true in sagittal plane recurvatum deformities with anterior ankle joint overload due to anterior talus translation[5]. Intraoperatively, peripheral nerve lesions may be present in the lateral incision (sural nerve lesion), anterior incision (deep peroneal nerve lesion), and medial incision (saphenous nerve lesion). In varus ankle correction with varus correction for valgus, we can have tibial nerve stretching and the development of acute tarsal tunnel syndrome, which is a concern, especially in patients with adhesions due to previous surgeries[5].

Results

Several studies have shown good clinical and radiographic results with supramalleolar osteotomy for treating varus ankles[10,31-34] and valgus ankles[22,26]. Krahenbuehl et al.[11] reported the outcomes of 294 supramalleolar osteotomies, demonstrating an 88% survival rate over five years. The best results were observed in patients under 60 years and in those with early-stage OA (Takakura grades 1, 2, and 3a). With a mean follow-up of five years (2 to 16 years), 13% of patients (38/294) evolved to severe ankle OA, having undergone ankle arthroplasty (30 patients) or ankle arthrodesis (8 patients)[11]. Tanaka et al.[12] found a similar result, reporting that good results of supramalleolar osteotomy occur in Takakura classification grades 1, 2, and 3a[12]. However, Lee et al.[32] found a different result, reporting that patients classified as Takakura 3b in the preoperative period had radiographic improvement, being graded as Takakura 2 in the postoperative period[32]. Pagenstert et al.[35] reported a study with 35 patients with five years of follow-up after supramalleolar osteotomy, and 91% of patients did not submit to arthroplasty or ankle arthrodesis[35].

Preoperative TT equal to or greater than 7° has been considered a worsening factor in results; however, Choi et al.[36] report 31 patients with varus OA and mean TT of 12.1° where, despite of showing no significant radiographic improvement (TT from 12.1° preoperatively to 9.9° postoperatively), patients showed improvement in clinical results. Additionally, patients who underwent correction with supramalleolar osteotomy and inframalleolar correction had better results than patients who underwent supramalleolar osteotomy only[36].

Although complete radiographic correction of the TT is not achieved, clinical improvement occurs in most patients with surgery[37]. These results suggest that the clinical outcome is independent of complete radiographic anatomical correction.

Mann et al.[21] report that, in cases with relevant intra-articular defect of the tibial plafond, the association of plafondplasty with supramalleolar osteotomy was superior to performing isolated plafondplasty, suggesting that the combination of the two osteotomies would be the best option for these complex cases[21].

Nuesch et al.[38] compared the gait of patients submitted to supramalleolar osteotomy for varus ankle realignment to that of controls with seven years of follow-up; patients had a slower gait and lower mobility in the sagittal plane. Despite the changes in gait, the patients' quality of life was considered good[38].

With short or medium follow-up, only 10% of patients submitted to supramalleolar osteotomy required ankle arthroplasty or arthrodesis[5].

Factors that increase the failure rate in supramalleolar osteotomy are age above 60 years, TT equal to or greater than 7°, postoperative joint incongruence, and ligament instability[9,11,12,33,37].

Conclusion

Supramalleolar osteotomy is an alternative for the treatment of asymmetric ankle OA. The osteotomy type depends on the deformity level, the type of fixation to be used, the quality of the soft tissue envelope, and whether the deformity is congruent or incongruent. The best results occur when the indication is made for treating Takakura grades 1, 2, or 3a, with 82% survival at 10 years. Worsening factors in results are age above 60 years, preoperative TT equal to or greater than 7°, preoperative OA degrees Takakura 3b or 4, and postoperative joint incongruence.

Inframalleolar deformities occur due to the shape of the calcaneus, the shape and orientation of the subtalar joint, and forefoot deformities. The effect of a calcaneus osteotomy on the ankle is not predictable, as it depends on the behavior of the coronal plane of the subtalar joint. The medial column of the foot must be evaluated preoperatively; an unstable medial column provides the flatness of the foot and, thus, the lateral weight-bearing on the ankle, while a medial column with plantar flexion provides the cavism of the foot and, thus, an anteromedial weight-bearing on the ankle.

Authors' contributions: Each author contributed individually and significantly to the development of this article: PCC *(https://orcid.org/0000-0001-7388-7229) Conceived and planned the activities that led to the study, approved the final version, interpreted the results of the study, participated in the review process and approved the final version. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID).

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Special Article

Achilles tendon rupture: discussion and updates

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Abstract

Achilles tendon rupture is a common injury, especially in athletes and active individuals, that presents significant challenges in treatment and recovery. This article reviews current approaches, controversies, and recent advances in managing this condition. The ongoing debate between surgical and conservative treatment highlights the need for a personalized therapeutic choice, considering the nature of the injury and the patient's profile. While surgery traditionally offers lower re-rupture rates, advances in minimally invasive techniques and accelerated rehabilitation have demonstrated similar efficacy with fewer complications. Innovations such as biological therapies, extracellular matrix grafts, and functional immobilization devices are changing the treatment scenery, although their effectiveness is still under evaluation. In addition, tissue engineering, cell therapies, and remote monitoring research open new possibilities for improving healing and rehabilitation. Prospects include an increasingly personalized and technological approach with the potential to optimize outcomes and reduce re-rupture rates.

Level of evidence V; Expert opinion.

Keywords: Achilles tendon; Therapy; Orthopedics; Injury.

Introduction

Achilles tendon rupture is a common orthopedic injury that predominantly affects active adults, particularly those involved in sports that require explosive movements, such as jumping and running. This tendon, the strongest in the human body, connects the gastrocnemius and soleus muscles to the calcaneus, playing a crucial role in locomotion. Despite its robustness, the Achilles tendon is vulnerable to injury, especially in individuals with risk factors such as advanced age, sudden increase in physical activity, and use of certain medications, such as corticosteroids and fluoroquinolones(1).

Achilles tendon rupture has increased in recent decades, reflecting population aging and increased participation in physical activity. The injury is characterized by a partial or complete rupture of tendon fibers, resulting in acute pain, edema, and sudden loss of plantar function. Diagnosis is usually clinical, supported by imaging tests such as ultrasound and magnetic resonance imaging (MRI) to confirm the extent of the injury(2).

Managing Achilles tendon rupture remains controversial, with debates surrounding conservative versus surgical approaches. Traditionally, surgical treatment was considered the gold standard to minimize the risk of re-rupture and restore full function. However, advances in rehabilitation and functional immobilization techniques have demonstrated comparable results with nonsurgical treatment in certain patients, challenging established practices(3).

The objective of this article is to discuss the latest updates in the diagnosis, treatment, and prognosis of Achilles tendon rupture.

Methods

This study is a narrative review, and the search was conducted in PubMed, Scopus, and Web of Science databases to identify relevant articles published between 2000 and 2023. Search terms such as "Achilles tendon rupture," "treatment," "diagnosis," "rehabilitation," "re-rupture," and "complications"

Study performed at the Hospital Municipal Salgado Filho, Rio de Janeiro, RJ, Brazil.

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were used. The research was limited to studies in English. Articles that presented data on the diagnosis, treatment, and rehabilitation results of patients with Achilles tendon rupture were included. Studies that focused on different injuries or did not provide detailed information on clinical outcomes were excluded. The selected articles were reviewed, and the analysis included the diagnostic methods used, the therapeutic interventions described, the rehabilitation protocols, and the reported outcomes, such as re-rupture rates, return to physical activity, and associated complications.

The extracted data were organized into thematic categories to synthesize the information in a coherent and accessible way. Data synthesis included the comparison of different treatment approaches, analysis of complication risk factors, and discussion of current guidelines for managing Achilles tendon rupture.

Results and discussion

Physiopathology

Achilles tendon rupture occurs due to structural failure in the collagen fibers that make up this tendon, the strongest in the human body. The Achilles tendon is mainly formed by type I collagen, which provides resistance and the ability to withstand large tensile loads. It connects the gastrocnemius and soleus muscles to the calcaneus bone, essential in transmitting the force required for plantar flexion, allowing movements such as walking, running, and jumping[1].

The physiopathology of Achilles tendon rupture is closely linked to biomechanical, degenerative, and vascular factors. In biomechanical factors, the Achilles tendon is subjected to repetitive forces and high loads, particularly during explosive movements such as running and jumping. These forces can lead to cumulative microtraumas, compromising the tendon's structural integrity. When the tendon is compromised, an abrupt movement or excessive load can rupture[2].

Tendon degeneration, known as tendinopathy, is a common predisposing factor for Achilles tendon rupture. With aging, the Achilles tendon can undergo degenerative changes, including disorganization of collagen fibers, increased extracellular matrix (ECM), and decreased vascularization. These changes compromise tendon resistance and increase susceptibility to ruptures, especially in individuals over 30 years of age, who are more likely to present these degenerative changes[3].

Vascular factors also play a significant role in the pathophysiology of Achilles tendon rupture. The tendon region, known as the "hypovascular zone" or "critical zone," located approximately 2 to 6 cm above the calcaneal insertion, has relatively poor vascularization, which limits the supply of nutrients and oxygen to the tendon fibers. This vascular deficit can contribute to degeneration and inadequate tendon healing, facilitating the development of rupture[4].

In addition, extrinsic and intrinsic factors can influence the risk of rupture. The use of corticosteroids and fluoroquinolones has been associated with an increased risk of tendon injury due to their negative impact on collagen synthesis and cellular function within the tendon. Obesity, diabetes, and chronic inflammatory diseases can also affect Achilles tendon health, increasing the likelihood of rupture[5].

Diagnostic

Early and accurate diagnosis of Achilles tendon rupture is essential for effectively managing the injury and optimizing functional outcomes. The rupture can be partial or complete, and the diagnostic approach must be thorough to differentiate between these conditions and other injuries that can mimic the symptoms[6].

The initial diagnosis is often based on clinical evaluation, which includes a detailed patient history and a focused physical examination. Patients with Achilles tendon rupture usually report the sensation of a sudden "pop" or sharp pain in the posterior region of the leg, followed by difficulty or inability to walk. Physical examination may reveal characteristic signs, such as edema, hematoma, and a palpable tendon defect, approximately 2 to 6 cm above the calcaneal insertion[7].

Two clinical tests are widely used to confirm the diagnosis:

Thompson's test: During this test, the patient is positioned in prone position with their feet hanging. Calf compression should normally cause plantar flexion of the foot. The absence of movement suggests a complete Achilles tendon rupture[4].

Matles Test: With the patient in prone position, the knees are flexed at 90 degrees. In a complete Achilles tendon rupture, the affected foot tends to be more neutral or dorsiflexion than the contralateral foot. Although the clinical diagnosis of Achilles tendon rupture is often reliable, imaging tests are useful, especially in cases of partial ruptures or when clinical findings are inconclusive[5].

Ultrasound is a valuable and widely available diagnostic tool that allows direct visualization of the Achilles tendon. It can identify disruptions in tendon fibers, intratendinous hematomas, and the extent of the rupture. In addition, dynamic ultrasound can assess residual tendon function during muscle contraction[6].

MRI is the gold standard for diagnosing Achilles tendon ruptures, especially in complex injuries or when surgical intervention is planned. MRI provides detailed images of tendon anatomy, allowing the evaluation of rupture extent, the degree of tendon retraction, and the condition of surrounding tissues. It is particularly useful in identifying partial injuries and planning surgery [7].

Although plain radiography does not directly visualize the Achilles tendon, it may be useful to exclude associated fractures, such as calcaneal fracture, or to detect bone avulsions that may be present in acute tendon injuries[8].

Treatment options

Managing Achilles tendon rupture involves choosing between conservative and surgical treatment, both with advantages and disadvantages. The therapeutic decision depends on several factors, including the patient's age, level of physical activity, extent of injury, and individual preferences. Treatment choice should be guided by a careful risk-benefit assessment, considering long-term functional outcomes and potential complications[9].

Conservative or non-surgical treatment involves immobilizing the affected limb to allow natural tendon healing. This approach is often indicated for less active or elderly patients, for whom the surgical risk is high or in cases of partial injuries[10].

Traditionally, conservative treatment consisted of immobilizing the ankle in an equine position (plantar flexion) for six to eight weeks, followed by rehabilitation. However, more modern approaches use walking boots or functional casts that allow progressive adjustments of the ankle position, facilitating early controlled movement and tendon healing[11].

Recent studies suggest that early mobilization under protection, rather than prolonged immobilization, can improve functional outcomes and reduce recovery time without increasing the risk of re-rupture. Rehabilitation protocols that include stretching and progressive strengthening exercises are critical to restore tendon function and prevent muscle atrophy[12].

Conservative treatment has been associated with slightly higher re-rupture rates compared to surgical treatment, although the difference is minimized with early rehabilitation protocols. However, the absence of surgical scars and the lower incidence of surgery-related complications, such as infections and adhesions, are significant advantages of this approach[13].

Surgical treatment is generally recommended for young, active patients or athletes who wish to return to a high level of physical activity. Surgery is considered effective in reducing the risk of re-rupture and restoring the strength and function of the Achilles tendon[14].

Surgical Achilles tendon repair can be accomplished through open or minimally invasive approaches. In the open technique, the surgeon makes a larger incision to expose and suture the ruptured tendon ends. Alternatively, minimally invasive techniques, such as percutaneous repair, use smaller incisions and special instruments to suture the tendon, resulting in a lower risk of infection and smaller scars[15].

Postoperative management involves initial ankle immobilization in plantar flexion, followed by a progressive rehabilitation protocol. Early mobilization is encouraged in modern protocols, aiming at rapid functional recovery and return to physical activity. Although surgery reduces the risk of re-rupture, it is not without complications. Potential complications include infection, wound healing problems, adhesions, and nerve injury. The surgeon's experience and the proper selection of patients are crucial to minimize these risks[8].

Studies show that surgical treatment offers better results regarding tendon strength and return to pre-injury activity levels, especially in athletes. However, the difference from conservative treatment tends to be small when modern early rehabilitation protocols are used[10].

Considering the patient's profile and expectations, the choice between conservative and surgical treatment must be individualized. Although surgical treatment is preferred for active patients who require complete recovery of strength and function, conservative treatment is a viable option for patients with less physical demand or who wish to avoid the risks associated with surgery[9].

Recent advances in treating Achilles tendon rupture include biological repair techniques, such as applying growth factors and ECM grafts, which aim to improve tendon healing. In addition, new immobilization devices that allow early mobilization are being developed to optimize functional recovery[15].

Rehabilitation protocols

During the first few weeks after injury or surgery, the goal is to protect the tendon from excessive stress and allow healing to begin. At this stage, the ankle is usually immobilized in a plantar (equine) flexion position using an orthopedic boot or cast. The weight-bearing on the affected limb can be limited or adapted with crutches. Active plantar flexion and dorsiflexion movements are avoided to protect tendon repair[11].

At this stage, protected mobilization is initiated to prevent stiffness and promote targeted healing of the collagen fibers. The immobilization position is gradually adjusted to allow for greater dorsiflexion. Passive and active assisted range of motion exercises focus on controlled dorsiflexion and plantar flexion movements. Partial weight-bearing may be allowed, progressing to full load as healing progresses[14].

At this stage, emphasis is placed on restoring strength and beginning functional activities. Isometric and isotonic strengthening exercises are introduced for the calf muscles, gradually progressing to more challenging exercises such as heel lifts. The full range of motion of the ankle is slowly restored, and the full-weight-bearing should be achieved. Agility and proprioception movements are also incorporated to improve neuromuscular control[13].

The final phase of rehabilitation focuses on preparing the patient to return to normal and sporting activities. Plyometric exercises, strength and resistance training, and activities specific to the patient's sport or occupation are progressively introduced. The goal is to ensure that the patient fully regains tendon function with comparable strength and flexibility to the unaffected side. Return to sport is normally allowed between four to six months after injury or surgery, depending on individual recovery[16].

The modern approach to Achilles tendon rehabilitation favors early mobilization under protection, challenging the traditional practice of prolonged immobilization. Studies have shown that early mobilization can reduce the risk of joint stiffness, accelerate functional recovery, and improve the quality of tendon healing without significantly increasing the risk of re-rupture. This approach is now widely adopted in both conservative and surgical protocols, with the adaptation of immobilization and weight-bearing according to the clinical progression of the patient[12].

Physiotherapy plays a central role in rehabilitating the Achilles tendon, providing expert guidance for each phase of the recovery process. An experienced physical therapist can adjust exercises and activity progression to avoid complications, such as re-rupture or adhesion formation while promoting proper healing. Regular clinical monitoring is essential to assess patient recovery, adjust the rehabilitation protocol as needed, and detect any signs of complications early[17].

Rehabilitation can vary between athletes and non-athletes, with specific adaptations to meet the functional demands of each group. In athletes, rehabilitation tends to be more intensive and focused on returning to high sports performance, including sports-specific training, advanced plyometric exercises, and future injury prevention strategies. In contrast, for non-athletes, rehabilitation may focus more on restoring function to daily activities and preventing re-rupture, with a more conservative pace of progression[16].

Prevention of re-rupture and other complications, such as chronic tendinopathy or persistent muscle weakness, is a crucial goal of rehabilitation protocols. Adherence to a structured and personalized rehabilitation program and ongoing medical follow-up are critical to ensuring a full recovery. Even after returning to normal activities, patient education about continuous rehabilitation is essential to prevent relapses and optimize long-term outcomes[18].

Complications and prognosis

Although a treatable injury, Achilles tendon rupture may be associated with several complications that influence the patient's prognosis. Proper management of these complications is essential to optimize functional outcomes and ensure complete recovery. The prognosis of the injury depends on several factors, including the type of treatment, adherence to the rehabilitation protocol, and the presence of comorbidities[17].

One of the most feared complications after Achilles tendon surgical repair is infection, which can range from superficial to deep. Deep infections can compromise the integrity of the tendon suture, leading to re-rupture or tendon necrosis. The prevention of infections involves rigorous aseptic surgical techniques and adequate postoperative wound care[19].

Complications such as wound dehiscence and formation of hypertrophic or keloid scars may occur, particularly in patients with risk factors such as diabetes or poor circulation. These complications may delay rehabilitation and require additional interventions, such as surgical revision or healing therapy[18].

The formation of adhesions around the repaired tendon can limit the ankle's range of motion and affect muscle function. Early mobilization and targeted rehabilitation techniques are crucial to minimize the risk of adhesions. Injuries to the posterior sural or tibial nerves may occur during surgery, resulting in painful neuropathies or paresthesias in the affected area. Although rare, these injuries can be debilitating and require specialized treatment, including pain management therapy[19].

The main complication associated with conservative treatment is tendon re-rupture, especially if the immobilization and rehabilitation protocol are not strictly followed. Studies indicate that early mobilization with adequate protection can reduce the risk of re-rupture, compared to prolonged immobilization[20].

Patients treated conservatively may experience residual weakness or functional deficit compared to the contralateral side, particularly in activities that require explosive force, such as running or jumping. Strengthening protocols and prolonged rehabilitation are essential to improve functional outcomes[21].

Some patients may develop chronic tendinopathy, persistent pain, and inflammation, even after tendon healing. This condition may result from improper healing or altered ankle and foot biomechanics. Management involves physiotherapy, activity modifications, and, in some cases, additional interventions such as platelet-rich plasma (PRP) injections[22].

The prognosis after an Achilles tendon rupture depends on several factors, including the patient's age, the level of physical activity before the injury, and the type of treatment received. Most patients can regain Achilles tendon function with appropriate treatment and intensive rehabilitation. However, the return to full sports ability may take six to 12 months, depending on the injury's severity and the treatment response [23].

The rate of Achilles tendon re-rupture is generally lower in surgically treated patients, especially compared to conservative treatment. However, with modern rehabilitation protocols, the difference in re-rupture rates between the two treatment methods has decreased significantly[24].

Post-injury quality of life may be affected by the complications above. Patients suffering from complications such as residual weakness, chronic pain, or infections may face ongoing challenges in their daily and sporting activities[25].

Athletes and physically active individuals wishing to return to high-impact sports may encounter challenges in recovery. Success in this return depends on extensive rehabilitation and the absence of significant complications. Rehabilitation directed towards sport and gradual reintegration is essential to prevent new injuries[26].

Strict adherence to the prescribed rehabilitation protocol is a major determinant of success in treating Achilles tendon rupture. Patients who follow medical guidelines tend to have better functional outcomes and a lower risk of complications. Conditions such as diabetes, obesity, and vascular disease can compromise tendon healing and increase the risk of post-treatment complications. Proper management of these comorbidities is essential to improve prognosis[27].

In cases of surgical treatment, the surgeon's experience and the choice of surgical technique are critical factors that influence the results. Experienced surgeons are more likely to avoid intraoperative complications and achieve durable repairs.

Effective management of complications associated with Achilles tendon rupture and adoption of evidence-based rehabilitation protocols are critical to optimize patient prognosis. Although conservative and surgical treatment can lead to good functional outcomes, the treatment choice should be personalized, considering the individual characteristics and the associated risk factors. Complete recovery is possible with careful planning and a multidisciplinary approach that includes surgery, physical therapy, and continuous clinical follow-up[(28)].

Recent advances and innovations in treatment

In recent years, the treatment of Achilles tendon rupture has evolved significantly, driven by technological advances, new surgical approaches, and the development of more effective rehabilitation techniques. These advances aim to improve clinical outcomes, reduce recovery time, and minimize injury-associated complications. The following discusses some of the major advances and innovations transforming the treatment of Achilles tendon rupture[(28)].

Percutaneous Achilles tendon repair is a surgical technique that involves making small incisions along the ruptured tendon, allowing suturing of the extremities without needing a large incision. Compared to open surgery, this technique has been associated with lower complication rates, such as infections and healing problems. In addition, percutaneous repair better preserves local vascularization and reduces the risk of adhesion[(21)].

Intraoperative ultrasound to guide Achilles tendon repair allows for accurate visualization of tendon structures, aiding in the correct placement of sutures and minimizing the risk of injury to adjacent structures. This approach can improve surgical outcomes and reduce re-rupture rates[(25)].

Biological therapies, such as applying growth factors and PRP, have gained prominence in treating tendon injuries. These substances are used during surgery or rehabilitation to promote tendon healing, accelerate recovery, and improve the quality of scar tissue. Preliminary studies suggest that PRP may reduce recovery time and improve functional outcomes, although more research is needed to establish standardized protocols[(8)].

Another promising innovation is using ECM grafts to enhance Achilles tendon repair. These grafts, composed of collagen and other structural proteins, can be implanted during surgery to provide additional tendon support and promote tissue regeneration. ECM has shown a potential to improve the resistance of the repaired tendon and reduce the risk of re-rupture[(23)].

Modern immobilization devices such as adjustable walking boots and dynamic orthotics replace traditional rigid immobilization methods. These devices allow for gradual adjustments in ankle position, facilitating early mobilization and promoting more functional tendon healing. The gradual transition to full-weight-bearing is an important feature of these devices, which helps reduce recovery time and improve functional outcomes[(2)].

The development of accelerated rehabilitation protocols, which promote early mobilization under protection and progressive strengthening exercises, has challenged the traditional paradigm of prolonged immobilization. These protocols have successfully reduced recovery time, minimized muscle atrophy and improved the quality of tendon healing. Rehabilitation guided by experienced physiotherapists is essential for the success of these programs[(15)].

Wearable devices such as motion sensors and smart footwear enable continuous monitoring of ankle mobility and weight-bearing during rehabilitation. These devices provide real-time data that can be used by physical therapists and physicians to adjust the rehabilitation protocol according to the patient's recovery, preventing complications and optimizing the return to activity[(7)].

Prevention programs focusing on neuromuscular training and strengthening calf and ankle muscles are gaining relevance, especially for athletes and active individuals. These programs aim to improve proprioception and motor control, reducing the risk of primary and recurrent Achilles tendon injuries[(24)].

Continued research in biomaterials, cell therapies, and tissue engineering promises to bring new approaches to treating Achilles tendon rupture. The development of artificial tendons and the application of stem cells for tissue regeneration are promising areas that, in the future, may revolutionize the treatment of this injury[(28)].

Conclusion

Achilles tendon rupture is a challenging injury that requires a carefully considered therapeutic approach to optimize clinical outcomes. The ongoing debate between surgical and conservative treatment reflects the complexity of clinical decision-making, highlighting the need to personalize treatment based on the individual characteristics and the specificities of the injury. Although surgical treatment has traditionally been preferred due to lower re-rupture rates, recent advances in minimally invasive techniques and accelerated rehabilitation protocols are changing the therapeutic scenery.

Innovations such as biological therapies, ECM grafts, and functional immobilization devices offer new opportunities to improve functional outcomes and reduce complications associated with the treatment of Achilles tendon rupture. However, the lack of consensus on the effectiveness of these approaches and the variability in clinical outcomes point to the need for more robust and high-quality studies.

Prospects are promising, with research focused on personalizing treatment, applying cell and biomaterial therapies, and developing wearable technologies for continuous rehabilitation monitoring. Integrating these innovations can improve patient recovery and prevent further injury, especially in high-risk populations such as athletes.

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Special Article

Achilles tendon injuries in high-performance athletes: from tendinopathies to rupture!

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Abstract

Objective: To synthesize the current literature on Achilles tendon injuries, focusing on incidence, risk factors, diagnostic methods, and decision-making regarding various treatment options in high-performance athletes.

Methods: A search was conducted on PubMed, Scielo, and Scopus databases from 2010 to 2023 using inclusion criteria for studies with athletes and focusing on Achilles tendon injuries.

Results: The incidence of Achilles tendon ruptures is approximately 15% among athletes in high-impact sports. Conservative and surgical interventions have shown that individualized treatment plans optimize recovery and prevent the recurrence of injuries.

Conclusions: Emerging rehabilitation techniques and surgical interventions have demonstrated a positive impact on the outcomes of returning to sport, offering a comprehensive view of the professionals involved in the care of this group.

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

Keywords: Achilles tendon; Tendon injuries; Athletics injuries; Rehabilitation; Rupture.

Introduction

The Achilles tendon, the popular and already established name of the calcaneus tendon, is a robust structure composed mainly of type I collagen, proteoglycans, other structural proteins, and water, providing strength and elasticity. It is the largest and strongest tendon in the human body, with a an average length of 15 cm, formed by the union of fibers from the gastrocnemius and soleus muscles. It's vascularization is derived from the peritendinous vessels originating from the posterior tibial and fibular arteries. Also, it is innervated by the tibial nerve. The area with the least vascularization lies between 2 and 6 cm near the insertion in the calcaneus, where its rupture occurs most frequently[1]. Achilles tendon injuries are among the most common musculoskeletal injuries found in athletes, especially those enganged in high-impact sports, such as athletics (36%), or the ones requiring sudden stops and rapid change of direction, such as basketball (20%) and football (5%). The tendon's limited vascular supply, combined with the repetitive biomechanical stress of sport, makes it highly susceptible to injury[1,2].

Biomechanical factors play a crucial role in Achilles tendon injuries, and inadequate movement patterns, especially in running and jumping, contribute significantly to the risk. Epidemiological data indicate that in the general population, Achilles tendon injuries predominantly affect individuals between the 3rd and 4th decades of life, with a ratio of approximately 2:1 between men and women. However, there is a marked increase among athletes, predominantly in women and athletes aged 27 to 31, particularly during the later stages of their careers. The frequency of tendinopathy is between

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1% and 2% in elite adolescent athletes and can reach 9% in recreational athletes. Studies have reported a cumulative incidence of approximately 24% in athletes[2-4].

The aim of this review is to provide a comprehensive analysis of the existing literature on Achilles tendon injuries in athletes. The focus is on epidemiology, risk factors, diagnostic methods, and decision-making among the various treatment options. By synthesizing current research, this review offers insights into best practices for prevention, surgical or non-surgical treatment, and rehabilitation, emphasizing the need for individualized approaches to optimize outcomes and minimize the risk of new injuries. In addition, the review discusses emerging trends in therapeutic interventions and their potential impact on athletic performance and return to sport[2,5].

Diagnosis, clinical and functional evaluation of Achilles tendinopathies

The diagnosis of Achilles tendon injuries is mostly clinical, based mainly on physical examination. The evaluation of Achilles tendon injuries in the high-performance athlete goes far beyond simply diagnosing the specific condition involving the tendon, encompassing a combination of clinical evaluation, semiological tests, and basic imaging tests for any patient. The clinical history of pain in the posterior region of the calcaneus, of gradual or acute onset with a “popping,” “stinging sensation,” or local trauma, are important diagnostic signs[2,6].

It is essential to differentiate between insertional and non-insertional injuries, as their clinical presentations, treatment, and prognosis are distinct. Insertional Achilles tendinopathy typically presents with pain and morning stiffness on the calcaneus, especially at the enthesis, where the tendon inserts into the calcaneus. It may or may not be associated with Haglund’s deformity, posterior enthesophyte (“spur”), or swelling due to tendinosis with varying degrees of micro-tears, causing discomfort during running or jumping. Non-insertional injuries occur mainly in the middle portion of the tendon and usually present with more significant pain and swelling in the tendon body and with a history of gradual onset, often related to increased physical activity[2,3].

The clinical examination should check for localized pain on palpation, increased body volume or at the Achilles tendon insertion, any local “gap,” swelling, and reduced range of motion or strength. The inability of monopodal support in the “tip of the foot,” even with physiological equinus and no apparent local “gap,” may suggest partial ruptures, especially when associated with insertional tendinopathy[2].

The Silfverskiold test is an essential tool for assessing the flexibility of the gastrocsoleus complex. By evaluating the range of motion and elasticity of the tendon, it can be determined whether it has the necessary flexibility to endure the repetitive stresses imposed by athletic activities or a shortening (functional equinus). Reduced flexibility can often occur during physical examinations, making this assessment crucial for prevention and rehabilitation strategies[7,8].

Total tendon rupture is typically diagnosed based on a reported snapping sensation, often described as a “stoned sensation” in the calcaneus, accompanied by three clinical findings that collectively offer high sensitivity and specificity. Palpation revealing a gap in the tendon topography and the classic Thompson and Matles physical tests are particularly significant in this diagnostic context and are well-established methods for confirming a total rupture. Thompson test, performed by squeezing the calf while the patient is in a prone position with the feet hanging from the examination table, evaluates the integrity of the Achilles tendon; no plantar flexion suggests a complete rupture. In the Matles test, the patient needs to flex the knee at 90º while in the same decubitus position. An Achilles tendon rupture will cause the foot to assume a more neutral position instead of maintaining slight physiological plantar flexion. Clinical evaluation is essential and often sufficient for diagnosing tendon rupture[2,6,9].

Imaging tests such as ultrasound and, preferably, magnetic resonance imaging are part of the therapeutic assessment. They are essential for high-performance athletes to confirm the diagnosis and better assess the type and extent of the injury, guiding treatment decision-making. Radiographs help evaluate any association with Haglund’s syndrome and rule out intra-tendinous or insertional calcifications[2] (Figure 1).

Diagnosis, clinical, and functional evaluation of high-performance athlete

The professional should be familiar with multidisciplinary assessments involving a comprehensive understanding of pathophysiology and biomechanics, physiotherapy, physical preparation, and sports physiology, considering the underlying biomechanical factors contributing to the injury.

A detailed assessment of the mechanical axis, the balance of muscle forces, degrees of flexibility, and restrictions of joint movements, ankles, and feet is crucial to develop a targeted treatment plan that addresses the primary causes of the injury, especially in athletes, and not only the local treatment of Achilles tendinopathy.

The biomechanics of Achilles tendon injuries involve intrinsic and extrinsic factors. The Achilles tendon is subjected to significant mechanical loads during running, jumping, and accelerating activities. It is essential for effective management, such as sports nutrition and physiology, in which being overweight influences biomechanical overload[2,10].

Lunge test and ankle dorsiflexion restriction assessments

The Lunge test is a valuable tool for assessing ankle dorsiflexion restriction, often implicated in Achilles tendon injuries. The test is performed with the patient standing upright, aligning the second toe with the front axis while positioned in front of a wall. The dorsiflexion angle is measured by instructing the patient to move their knee forward to touch the wall without lifting their heel from the ground. An average of three measurements is taken for each side, the ideal being about 40º of dorsiflexion[8].

Limited dorsiflexion can lead to compensatory mechanisms during gait and athletic activities, increasing tension in the Achilles tendon. Ensuring adequate dorsiflexion through targeted interventions can help reduce the risk of injury and improve functional outcomes in athletes[8].

Biomechanical and axis evaluation

Evaluating the mechanical axis is a fundamental part of the functional evaluation. It starts with a standard orthopedic clinical examination combined with static tools such as the podoscope and, preferably dynamically, such as the force platform of a kinetic assessment of the lower limbs and even motion analysis laboratories for a kinematic evaluation.

These evaluations provide information about deviations in valgus or varus alignment, type of steps and dysmetria, and functional due to deficits in strength, muscle fatigue, or joint flexibility, which may increase tension on the Achilles tendon. For the sake of natural selection and sports performance, we rarely encounter high-performance athletes with excessive mechanical axis deviations. Unlike other patients, the most common are functional deficits or subtle deviations[8].

Biomechanical factors predisposing to injury include quadriceps and gluteal muscle strength deficit, reduced impact absorption in running and jumping, abnormal foot alignment with excessive pronation or supination, and changes in gait mechanics. Excessive eccentric load increases tendon tension, especially when slowing down or running uphill activities. Biomechanical imbalances, such as reduced ankle dorsiflexion or restricted internal hip rotation, result in compensatory stresses on the tendon, increasing the risk of injury. Understanding these factors is crucial to developing effective preventive and rehabilitation strategies[8].

According to Aubol and Milner[11], two dominant biomechanical mechanisms exist for developing tendinopathies in running athletes. The "whip" mechanism occurs when runners exhibit excessive and prolonged eversion of the hindfoot, which causes the calcaneal tendon to undergo a "whip" movement. The "tearing" mechanism occurs when excessive contraction of the plantar flexor muscle at the beginning of the posture causes micro tears in the calcaneal tendon[11].

Muscle strength assessment

Several tools are used to assess the muscle strength of the lower limbs and the function of the Achilles tendon and gastrocsoleus complex. The following stand out:

Manual dynamometer

A portable isometric force meter for muscles associated with the Achilles tendon offers a cost-effective and practical solution for rapid clinical evaluations. These devices are particularly useful in a specialist's office for monitoring pre- and post-intervention outcomes[8].

Isokinetic dynamometers and training platforms (Cybex®, Kineo®)

The isokinetic dynamometer (Cybex®) evaluates muscle strength in controlled movement at constant speed, especially in the knee flexor and extensor muscles, and may have the specific variation for gastrocnemius and soleus, offering a detailed and reliable analysis of muscle performance and balance between agonists and antagonists. Kineo® is a platform that combines training with concentric and

Figure 1. T2-weighted MRI of the ankle comparing Achilles acute rupture types. Simple Achilles tendon (A) vs complex delaminative rupture (B).

eccentric endurance, assessing muscle strength and function during complex movements. The higher cost of these devices is a factor that restricts their use daily, so they are almost exclusive to high-performance sports centers[8].

NordBord hamstring testing® and force Frame®

Australian devices developed by Vald Performance are designed to assess the eccentric strength of the hamstring muscles and facilitate training with Nordic exercises (NordBord®). They also enable strength assessments of various core-related joints in the pelvic and hip regions, including the adductors, abductors, and rectus abdominis (Force Frame®), indirectly influencing the gastrocnemius and soleus regions and the Achilles tendon[8].

Hip mobility and biomechanical considerations

Hip mobility assessment, particularly internal rotation, is important in understanding Achilles tendon injuries. The hip-limited internal rotation can lead to compensatory movements that alter the biomechanics and sports movements with an external rotation gait of the lower limb and, consequently, a lateral overload on the foot, increasing the tension in this more lateral portion of the Achilles tendon. These biomechanical changes in a chronic way are particularly harmful, especially in the context of insertional tendinopathy in its central lateral portion, already under greater tension due to the anatomical issue of torsion of the Achilles tendon fibers of each component from the gastrocnemius or soleus[12].

Evaluation of movement in open and closed kinetic chain

The evaluation of open kinetic chain motion involves analyzing movements where the distal limb segment, such as the foot, is free to move, not attached to an object or surface. This contrasts with the closed kinetic chain, where the distal segment is fixed. Both methods are essential in assessing the Achilles tendon, as they help identify weaknesses, muscle imbalances, and specific strength deficits that could contribute to injuries or impair recovery[8].

Evaluation in force platform and gait laboratory

The closed kinetic evaluation on a force platform, such as Vald Performance's ForceDecks model, allows the analysis of different components during these jumping activities, such as concentric (when the muscle shortens) and eccentric (when the muscle stretches) contraction force, in addition to evaluating jump power, performance (height), and unilateral and bilateral movements. The reactive force index (RSI) functional algorithm is also used to measure the ability of the tendon and muscles to generate force quickly and efficiently during activities that involve stretching-shortening cycles and fatigue, such as repetitive jumping. The RSI is particularly important for assessing not only athletic performance but also risk of injury[8].

In selected cases, three-dimensional kinetic and kinematic analysis of movements may be necessary in a motion analysis laboratory, where several cameras with infrared sensors capture the movements of the lower limbs during activities such as gait and running, jumping and squatting on an instrumented treadmill with markers (Figure 2), being able to identify abnormal movement patterns that may predispose to Achilles tendon overload and injury. This assessment helps to understand how the athlete's body moves in specific activities and under fatigue, allowing the identification of muscle imbalances or compensations that can be corrected to prevent injuries. They may or may not be associated with an electromyographic evaluation to analyze the electrical activity of the muscles during movement. The electromyographic analysis is performed by placing surface electrodes on the muscles of interest, and electrical activity is recorded during dynamic activities such as running or jumping. It allows you to identify which muscles are being activated, at what intensity, and at what time during a specific activity. This analysis is especially useful in athletes to understand how the muscles of the gastrocnemius soleus complex and other muscles of the lower limbs, mainly hamstrings, quadriceps, and gluteus maximus, are contributing to movement and impact absorption, as well as whether there are abnormal activation patterns that may predispose to injury. These data

Figure 2. Gait lab analysis with 3-D motion capture.

help guide training and rehabilitation interventions, ensuring that muscles are activated correctly and efficiently[8].

Physiology of Achilles tendon injury

Achilles tendon injuries encompass a variety of conditions, including tendinopathy, partial ruptures, and complete ruptures. The pathophysiology of Achilles tendinopathy involves both degenerative and inflammatory processes. In chronic tendinopathy, the normal collagen I matrix is interrupted, with increased type III collagen and accumulation of extracellular matrix components, such as proteoglycans and glycosaminoglycans. These processes lead to the loss of the tendon's structural and functional integrity, which becomes macroscopically evident during surgical intervention. The intact fibers of the tendon exhibit an organized white appearance, contrasting with the grayish and duller aspect of the fibrous scar tissue present in areas affected by tendinosis or micro-ruptures. On microscopic examination, it is common to find a disorganized arrangement of collagen fibers, increased vascularization (neovascularization), and tenocytes with altered morphology[13,14]. From a histopathological point of view, edema and less neovascularization are more common in acute tendon injuries[14].

Structural changes lead to a lower capacity to withstand mechanical stresses and losses of elasticity. Due to its elastic properties, the Achilles tendon can stretch up to 4% of its length without injury. An elongation of 6% to 8% leads to microscopic rupture of the fibrils and from 8% to macroscopic failure[1,15].

Physiology of tendinopathy healing

The Achilles tendon healing process is complex and requires careful management at all stages to ensure a successful recovery. By aligning treatment and rehabilitation strategies with the biological stages of healing, we can optimize outcomes and help patients safely return to their activities[14,16].

Achilles tendon healing occurs in three main stages:

Inflammatory stage

This stage occurs immediately after the injury, for a few days, and is characterized by pain, edema, and, in some cases, hyperemia and local heat. Inflammatory cells, such as neutrophils and macrophages, migrate to the injury site to remove damaged tissue and release cytokines and growth factors, including IL6, IL10, COX2, and TGF-β1. These factors are essential to stimulate initial tissue repair. However, prolonged inflammation can lead to complications, such as chronic tendinopathy, characterized by a lower amount of inflammatory cells in the long term, as observed in chronic injuries than acute ones. In addition, early inflammation may involve the activation of neural and inflammatory markers, such as PGP9.5 and CD45, related to the pain and regeneration process. In practice, the difficulty is removing the high-performance athlete for the appropriate treatment at this time of minor injuries[13,14].

Proliferative stage

Tenocyte proliferation and tendon matrix reconstruction with type III collagen and other extracellular components occur during this stage, which lasts from days to weeks. New blood vessels form to nourish the healing tissue. However, the tendon remains weak, and rehabilitation must be careful to avoid new injuries or worsening, as the athlete often remains active and withdraws for treatment only in major injuries or when there is a loss of performance[14,17].

Remodeling stage

This final stage can last from months to stability in about two years, usually the final functional recovery time. In more extensive ruptures and chronic injuries, the tissue may present a denser and more compact structure, with common tendinous fatty infiltrations associated with edema and inflammation in the surrounding tissues, changing tissue conformity[14,16].

Introduction to treatment

Achilles tendon injuries are significant due to their potential impact on an athlete's mobility and performance and the financial loss from being away from activities. Effective treatment is crucial to ensure optimal recovery and prevent long-term complications, especially in minor injuries in which the athlete often remains active.

There are two main approaches to managing these tendinopathies: surgically and conservatively. The choice between these treatments depends on several factors, including the severity of the injury, the level of activity, whether or not the athlete's performance is maintained, and their overall health. Understanding the nuances of each approach is essential to personalize the best possible care and achieve successful results[5,9].

The conservative approach to treating Achilles tendon injuries involves several strategies that can be adjusted according to each patient's needs and clinical progression, performed until the athlete maintains performance, even with the injury. Soft tissue treatment was impacted by the PEACE and LOVE protocol[18] an acronym for Protection (P), Elevation (E), Avoid Anti-Inflammatories (Avoid), Compression (C), Education (E), and Load (L), Optimism (O), Vascularization (V), Exercise (E). Since then, we have been changing the concept, reducing the use of cryotherapy and stimulating vascularization with local heat techniques and greater local oxygen supply, evolving exercise protocols described in the middle of the last decade such as Alfredson[19] and "Heavy Slow Resistance" (HSR)[20] which were already widely used, currently level A of evidence mainly in cases of body tendinopathy, with variations for insertional tendinopathies[19,21].

Alfredson Protocol: preferred method for athletes who can maintain regular activity, with three sets of 15 repetitions of eccentric exercises twice a day for six consecutive weeks. This strengthening of the muscles applied daily reduces pain and effectively improves function in patients with tendinopathy[2,22].

"Heavy Slow Resistance" (HSR)[20]**:** involves high mechanical loads in slow and controlled resistance movements with concentric and eccentric exercises, applied three times a week for 12 consecutive weeks, effectively promoting tissue healing and improving tendon function. The load is adjusted according to the patient's progression, preferably with the athlete away from activities for treatment associated with other rehabilitation methods[20].

In addition, combining Alfredson and RSH protocols, adding core exercises at least twice a week, with the strengthening of the quadriceps and gluteus maximum and medius, migtht be advantageous, allowing the personalization of rehabilitation based on clinical evolution[23].

Advanced therapies adjuvant to treatment

Shock wave therapy (SWT): Uses high-intensity sound waves to promote mechanical microtrauma in biological tissue, promoting controlled tendon healing, effective in treating chronic tendinopathy, level B of evidence when associated with eccentric exercises in physiotherapy. It can be the radial model, which is more accessible, or the focal model, which is reserved for more severe cases and with the athlete's removal for treatment. Radial SWT can also be used for myofascial release, especially for Silfverskiold-positive athletes[24,25] (Figure 3).

High-Intensity laser therapy: The bio-stimulation and acceleration of cellular processes stimulated by the laser reduce inflammation, stimulate oxygen uptake and blood circulation, facilitate and accelerate healing, and contribute to pain reduction. Long-term efficacy is still under study, and the higher cost of the equipment restricts its use to high-performance athletes[12] (Figure 3).

Tissue Regeneration Therapy (Tecar®-Therapy®): Technique with high-frequency electromagnetic energy to promote tendon healing with increased circulation by deep heat, allowing dynamic association with manual therapy techniques for myofascial release and muscle strengthening exercises during its application, very important as activation before physical activities and often requested by high-performance athletes for the feeling of well-being and rapid response, but which still requires further studies to confirm its long-term effectiveness[8] (Figure 3).

Figure 3. Adjuvant therapies for non-surgical treatment of Achilles disorders. (A) Extracorporeal shock wave therapy (B) High-intensity laser (C) Tecar Therapy (D) Intratissue percutaneous electrolysis.

Intratissue percutaneous electrolysis (EPI®): A technique described by Abat et al.[26] which uses a combination of mechanical (needles) and electrical (galvanic current) stimulation to promote a controlled reparative microinjury in the fibrocicatricial tissue area of the tendon, preferably guided by ultrasound images. It is also a therapy frequently used and requested by high-performance athletes due to the feeling of we ll-being and immediate analgesia for an active athlete, despite evidence still being limited to publications with small samples, clinical heterogeneity, and high risk of bias[27,28] (Figure 3).

Other physiotherapeutic devices, such as pulsatile ultrasound, LED light plates, magnetotherapy, and super inductive system (SIS®) with an electromagnetic field, in addition to the most diverse electrotherapy devices recently launched on the market, are part of the treatment in athletes. However, they still have limited evidence in isolation and may be more widespread in the future (Figure 4).

Pharmacological Interventions: There is no robust evidence to support the use of nonsteroidal anti-inflammatory drugs and systemic corticosteroids or in local infiltrations, with or without hyaluronic acid for treating Achilles tendinopathy, with limited benefits compared to conservative approaches. Intra-tendon infiltration is a risk for rupture and should not be performed, and peritendon hyaluronic acid may give some analgesia, even if transient[29,30].

Biologic therapies

The association of adjunct techniques such as platelet-rich plasma (PRP) infiltrations or stem cell therapy of iliac crest aspirates, whether pure (BMA) or concentrated (BMAC), have been studied to improve tendon healing and regeneration, with some satisfactory results mainly with the use of BMA for the non-surgical treatment of chronic insertional tendinopathies. The controversial PRP does not yet have scientific evidence, either for use in chronic tendinopathies or as an adjunct to treating acute ruptures and, so far, should not be indicated[9,31,32].

Thus, treatment selection should be based on the patient's individualized assessment, considering their response to treatment and the injury stage. The combination of conservative techniques and advanced therapies offers a comprehensive approach to Achilles tendon rehabilitation. The improvement in clinical outcomes with this treatment, especially for body tendinopathies in athletes, practically transformed in historical records surgical techniques described in the past, involving isolated tenoplasties, simple myofascial release, or Achilles paratendon. Surgery for chronic Achilles tendinopathies should be indicated when the athlete is losing physical or technical performance and has not responded to treatment with well-defined clinical protocols, which is why the surgeon is aggressive and thorough when he sees the need to change the treatment conduct[7,8].

Approach to total Achilles tendon ruptures

Decision-making when facing a total rupture of the Achilles tendon in an athlete is a highly controversial subject, even among sports trauma and foot and ankle surgery specialists. We have to be aware of the factors involved in the rupture, such as the age of the athlete (under 30 years, better prognosis), the specificity and position of performance in the sport practiced, the weight of the athlete (the authors follow

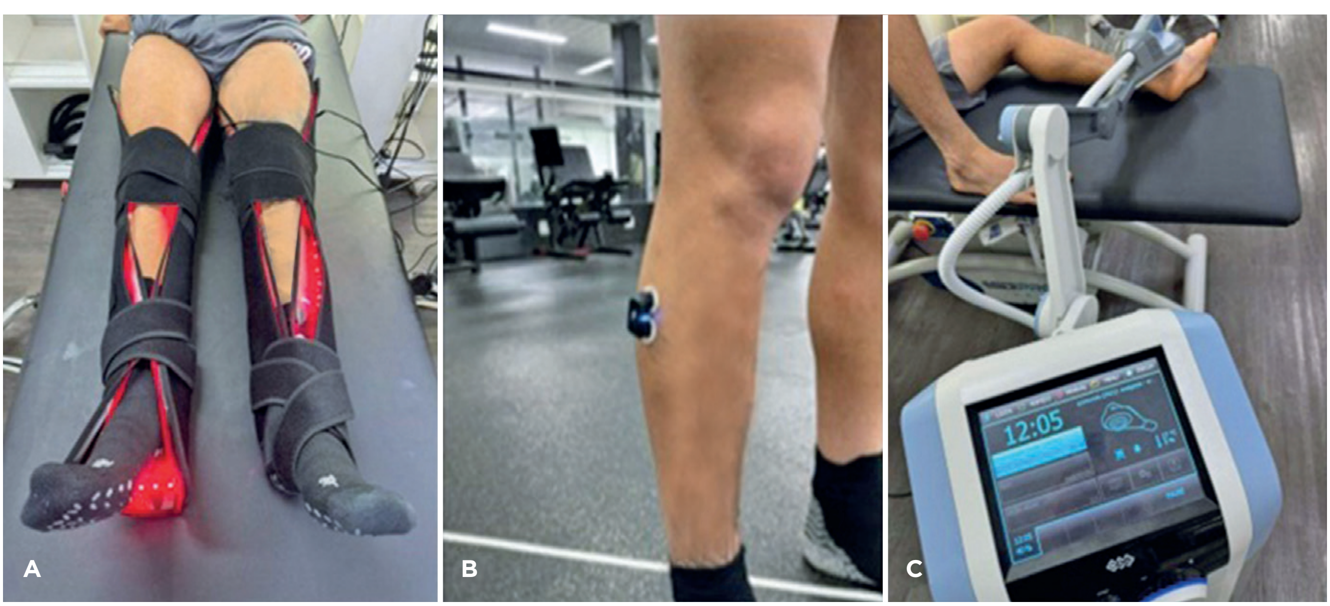

Figure 4. Devices used for athlete's management for prevention and treatment of Achilles disorders. (A) LED light therapy (B) Electromyography (C) Super inductive system®.

the Olympic division model between patients with less or over 90 kg of body weight), the tissue quality due to any previous tendinopathy, the rupture site (the lower and insertional the worse the healing potential), the rupture type (classic "cauda equina" in the body, proximal myotendinous junction, delaminative, insertional with or without spur avulsion or calcifications, complex), as well as factors such as associated diseases (autoimmune, diabetes), smoking (traditional or electronic cigarettes), peripheral arterial insufficiency and even the misuse of anabolic steroids by athletes who are not subject to frequent and more rigorous anti-doping tests (Figure 5).

Although the conservative treatment of total Achilles tendon ruptures has advanced since the publications of the functional method in the middle of the last decade, with equinus immobilization and protected early load, when discussing treatment in professional athletes, it is predominantly surgical, intending to restore tendon integrity and function quickly and with the least possible loss of flexibility, strength, and endurance in repair. Suppose conservative treatment is chosen for total ruptures, even due to potential patient preference. In that case, we must consider the presence of clinical criteria such as no pain or previous tendinopathy, the rapid start of treatment still within stage I of the biological healing process, a rupture in the tendon body, and a distance between the stumps of less than 5 mm in plantar flexion or 10 mm in neutral(8,16). A literature review showed that when appropriate criteria are met, conservative treatment can culminate in results comparable to surgical repair(13).

A meta-analytical review of Ochen in 2019(33) found no significant difference in re-rupture rates between surgical and conservative treatments, especially when mobilization and early loading protocols were employed. In addition, the risk of complications, such as wound infection and nerve damage, was significantly lower in the conservative group. The bias of these reviews is that among athletes, it is extremely common to report previous pain and the presence of tendinopathy to varying degrees, already being a reason for the contraindication of conservative treatment in this public of greater physical demand, different from the general population. Either way, informed decision-making is crucial. Patients should be educated about both approaches' potential risks and benefits, including the possibility of re-rupture, loss of tension through the indirect healing process, differences in rehabilitation time, and long-term functional outcomes(9,33,34).

The surgical management of Achilles tendon injuries is essential to restore the perfect tension and the quality of the tendon healing tissue after rupture, which are the main factors for adequate recovery of function, preventing performance loss and long-term complications. The choice of surgical technique depends on the type, time, and severity of the injury, as well as the functional demands and general health of the patient described above.

This section presents an overview of the main surgical approaches to Achilles tendon injuries, including open repair, percutaneous repair, and minimally invasive techniques, all supported by the latest literature(30,35,36).

Open repair

Open Achilles tendon repair is a well-established and classic method for treating complete ruptures and chronic tendinopathies. This technique involves a direct incision at the back of the ankle to access the damaged tendon, with excellent visualization and direct access to the tendon,

Figure 5. Different types of Achilles tendinopathy. (A) Simple midportion rupture (B) Complex delaminative rupture (C) Complex midportion and insertional rupture (D) Insertional with severe tendinopathy.

allowing accurate repair of the ruptured fibers. However, it is associated with a higher risk of wound complications and infection than less invasive methods[29,30,36,37] (Figure 6).

Key steps

Incision and exposure: A longitudinal incision is made along the back of the leg, which typically extends from just above the tendon insertion into the posterior tuberosity of the calcaneus to the middle part of the calf proximally. Careful dissection exposes the Achilles tendon, preserving the surrounding neurovascular structures[23,30,36].

Tenoplasty with debridement and repair: Any degenerated tissue is removed to expose the healthy tendon edges. The ruptured ends of the tendon are then united and sutured with non-absorbable suture (metalized polyester type FiberWire® Arthrex or UltraBraid® Smith & Nephew or similar from other manufacturers) or absorbable suture (Vicryl® 1.0 mm). Contraindications for single braided polyester threads (Ethibond®) are due to the high risk of inflammatory reaction and surgical wound complications due to the superficiality of the Achilles tendon. Techniques such as Krackow suture, modified Krackow with suture at a distance from the rupture focus (authors' preferences), and modified Kesller or Bunnell suture are commonly used to ensure a safe repair[29,30].

Rehabilitation and postoperative care: The leg is immobilized in physiological plantar flexion with a cast or orthosis in the postoperative period, facilitating tendon healing and with less local tension. The gradual introduction of load and rehabilitation exercises is performed according to the progress of healing, preferably with the assistance of a physiotherapist, who will perform the functional exercises early. The protected load is, so far, still controversial, despite evidence since the middle of the last decade that it stimulates growth factors with greater strength of resistance and speed in the biological healing process and the authors' preference for conducting the release after two to three weeks of surgery, provided that with adequate healing of the surgical wound[36,38].

Tendon reinforcements and transfers

Tendon reinforcement can be used to enhance the resistance of the repair, leading to good quality type I collagen in cases of extensive Achilles tendon ruptures with chronic degeneration, insertional just tendinopathies, delaminative ruptures, athletes weighing more than 90 kg (authors' opinion) or when the surgeon lacks complete confidence in a direct repair.

Reinforcement techniques include various tendon transfers described using autologous grafts, such as the flexor hallucis longus tendon, whether in a double (Wapner) or single (Wilcox, Hansen, Den Hartog), short peroneal (Turco, Teufler, Turco, and Spinela), thin plantar (Lynn), flexor digitorium longus (Mann, Clain, and Baxter), hamstring, either gracilis or semitendinosus, isolated or combined (Maffulli), which can be fixed in the calcaneus or sutured directly to the Achilles tendon to provide greater stability and mechanical strength in the repair. While effective, these grafts for reinforcement may increase surgical time and the complexity of the procedure.

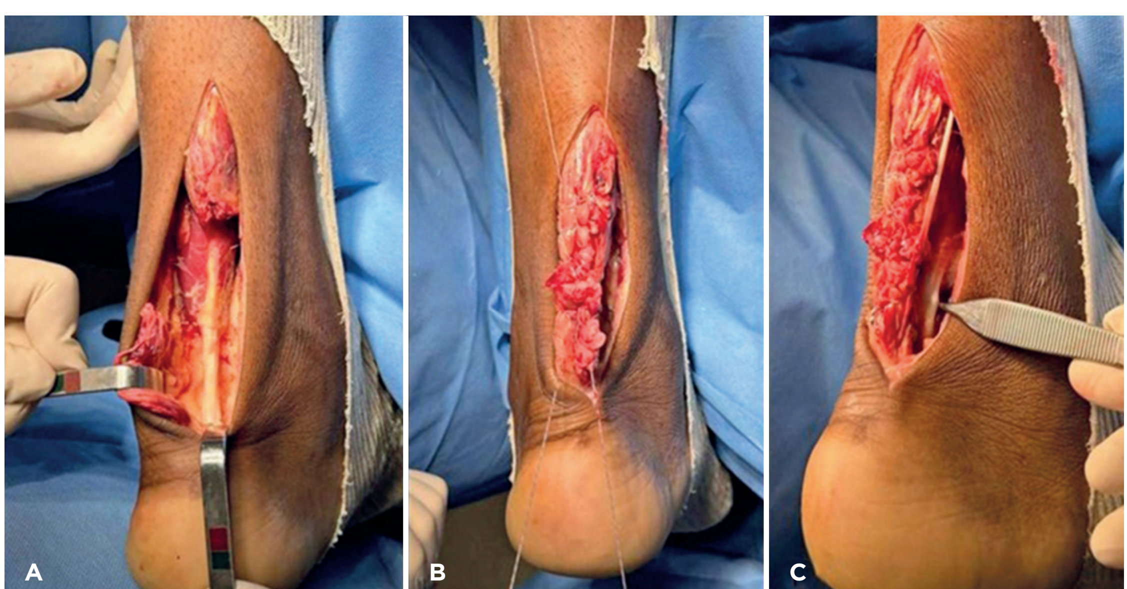

Figure 6. Open Achilles tendon repair in a soccer player with complete rupture with flexor hallucis longus tendon transfer and reinforcement of plantaris tendon. (A) Achilles tendon gap with associated flexor hallucis longus tendon transfer (B) Krakow suture of the tendon stumps (C) Final appearance.

The allograft are typically reserved for cases of failure in conventional techniques or in exceptional situations, such as in cases of re-rupture in athletes who have already used the grafts available for other reasons(9,22,36).

Since Wapner's publications in 1993(22), still using the dual route, the transfer of the flexor hallucis longus tendon has been widespread, being considered an excellent substitute even when the Achilles tendon is severely compromised due to its anatomical proximity and biomechanical function similar to the Achilles tendon. Currently, with the wide dissemination of the technique and the safety in the use of the single route for the transfer of flexor hallucis longus tendon, fixed in a bone tunnel in the calcaneus using an interference screw, we have additional support to the repaired Achilles tendon and promoting a functional recovery process without major secondary losses, even in athletes who require starting and jumping in their sports modalities, with minimal increases in surgical time and complexity(9,22,39).

Biological and synthetic materials

Biological materials, such as collagen matrices, fibrin-rich plasma (FRP) membranes, and other biomaterials, are being extensively studied. They can be used as adjuvants to support tissue regeneration and reinforce the healing process. Studies suggest that this biological material can help guide the growth of new tendon tissue, improving repair resistance over time, although robust scientific evidence is still lacking(32).

Alternatively, synthetic materials like polyester grafts, metalized polyester ribbons, or polypropylene can provide immediate structural support, especially in patients with significant tendon degeneration.. To date, this synthetic material is without evidence of improvement when publications are withdrawn without conflict of interest and may even be a source of calcaneal pain due to the different mechanical resistance with the biological tissue when under tension upon return to sport(9,10,13,37).

Percutaneous repair

Percutaneous repair is a less invasive alternative to open surgery, often used for acute and less complex ruptures of the Achilles tendon body. This technique involves small incisions to perform the repair through the skin, using a specialized set of instruments, including percutaneous needles or specific suture threads, with several techniques described since the first publications of Ma and Griffith in 1977,(40) without a devitalization of peritendon soft tissues, the need for tourniquet and the greater risk of surgical wound complications, but with greater complications of iatrogenic injuries in the sural nerve, loss of suture tension or re-rupture. The evolution of percutaneous repair methods, as in the studies of Webb and Bannister (1999)(41), Assal and Achillon (2002)(42), Carmont and Maffulli (2007)(43), as well as the introduction of instruments that allow intra-tendinous suture threads (Amlang et al., 2006)(44), or intra-tendinous and blocked in the stumps with specific guides (PARS Arthrex® 2012, Figure 7), reduced the risks of sural nerve injuries or re-rupture, especially when associated with the functional protocol with protected early load. After week three, postoperative conduction may be in the protected early load functional protocol. Still, percutaneous techniques may be less effective in cases when precise alignment and tendon tension are crucial, such as, in the authors' opinion, in athletes weighing more than 90 kg, extensive tendon degeneration,

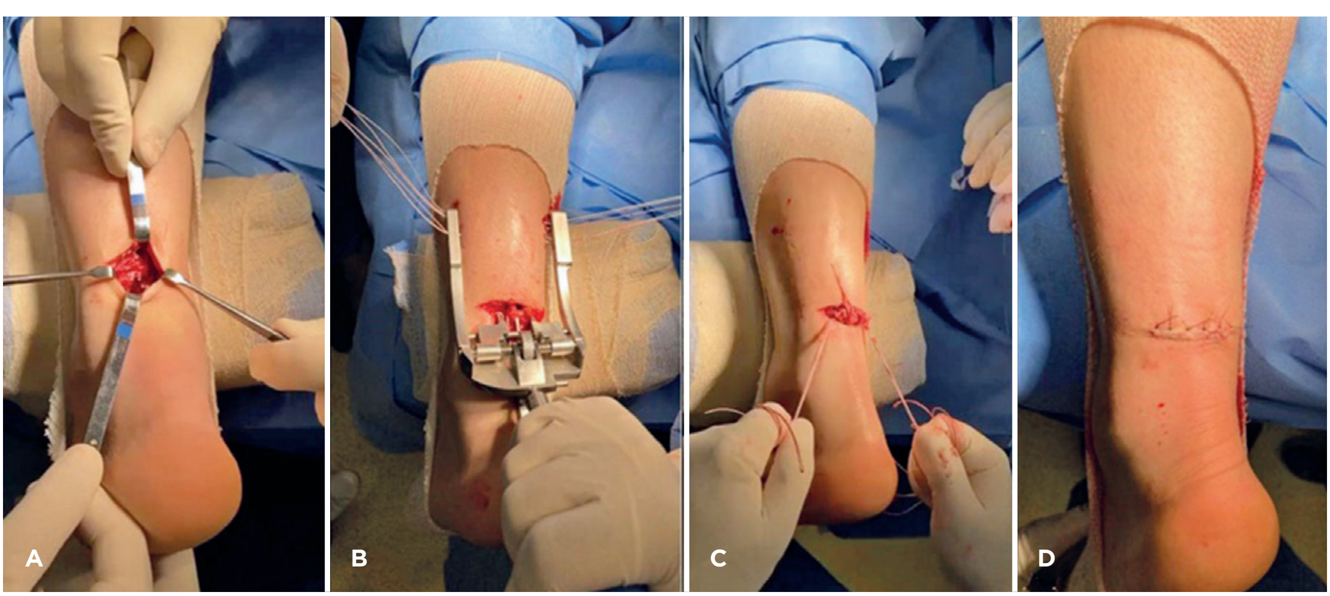

Figure 7. Minimally invasive Achilles tendon repair (PARS Achilles Jig System-Arthrex®) in a gymnastic athlete with complete rupture.

delaminative ruptures, or insertional tight ruptures with poor tissue mass quality for repair, even with modern specific tools and the use of guides with metalized polyester tapes and accessory fixation with anchor screws (PARS Speed Bridge Arthrex® 2019)[36,45].

Minimally Invasive Techniques

Minimally invasive techniques have gained popularity for their potential to reduce surgical trauma and speed recovery. These techniques range from percutaneous exostectomies of bony prominences, as in Haglund, to endoscopic tendon transpositions, either for chronic tendinopathies or for acute ruptures, as described in the study of Abdelatif and Batista[39], pointing out that this approach holds promise for the future, provided they are reproducible in other centers[39,46,47].

These techniques provide less postoperative pain, smaller incisions, and faster recovery. They are particularly suitable for patients with less extensive injuries requiring a faster return to activity[5,9,15,35,47].

Final considerations

The pathophysiology of Achilles tendon injuries reveals a multifaceted process of degeneration and inflammation that compromises the structural and functional integrity of the tendon. Understanding biomechanical changes and predisposing factors is crucial for both prevention and treatment. Diagnostic approaches that combine detailed clinical evaluation, semiological testing, and imaging are crucial for accurate diagnosis and to guide appropriate treatment.

The surgical approach to Achilles tendon injuries should be tailored to the injury's specific characteristics and the patient's needs. Open repair remains the gold standard for complex cases, offering direct access for proper tendon repair and tension, while percutaneous and minimally invasive techniques offer less surgical trauma and faster recovery for simpler cases. Advances in surgical techniques and biological therapies continue to improve the effectiveness of Achilles tendon repair, leading to better outcomes for patients. A thorough understanding of the nuances of each technique allows orthopedists to make informed decisions and optimize treatment strategies for Achilles tendon injuries.

High-performance sports may not be as healthy as recreational sports. A comprehensive understanding of Achilles tendon injuries in athletes, from pathophysiology and biomechanics to diagnostic and therapeutic approaches, is critical for effectively managing these complex conditions. Tendon injuries represent a significant challenge in orthopedic practice due to the high functional demand and biomechanical requirements imposed by the sport.

Achilles tendon injuries are frustrating for athletes and physicians, and some performance loss must occur after an injury, whether total or partial.

In short, an integrated, evidence-based approach to Achilles tendon injuries is essential to optimize clinical outcomes and long-term functionality. Continuous research and innovation in diagnostic methods and treatment strategies will improve the management of these injuries promoting effective recovery for affected patients.

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Review

Pseudoarthrosis treatment with stem cells: an integrative review

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Abstract

Objective: This integrative review aims to synthesize and critically analyze the current literature on the use of stem cells in the treatment of pseudarthrosis.

Methods: A systematic search was conducted in electronic databases, resulting in the inclusion of preclinical and clinical studies that investigated the impact of stem cells on bone healing.

Results: Proposed biological mechanisms include the ability of stem cells to promote osteogenic differentiation and secrete growth factors that facilitate tissue repair. Results indicate that stem cell treatment often increases rates of successful bone healing, improving functional outcomes and reducing postoperative complications. Limitations include the heterogeneity in treatment protocols and the need for randomized clinical trials to robustly validate these findings.

Conclusion: The use of stem cells emerges as a promising approach in the management of pseudarthrosis, promoting a new perspective in orthopedic regenerative medicine.

Level of evidence V; Expert Opinion.

Keywords: Pseudoarthrosis; Stem cells; Bone; Regenerative medicine; Treatment.

Introduction

Pseudarthrosis, or bone nonunion, is a significant complication after fractures and orthopedic surgical procedures, being characterized by the inability of the injured bone to heal properly. This condition challenges orthopedists and surgeons with its clinical complexities and substantial impact on patients' quality of life[(1)]. Traditionally, treatment involves conventional surgical techniques such as internal fixation with plates and screws, as well as autologous or allogeneic bone grafts. However, advances in regenerative medicine have introduced promising therapies, such as the use of stem cells, which have the potential to revolutionize the management of pseudarthrosis. Stem cells are undifferentiated cells with the capacity for self-renewal and differentiation into several cell types, including osteoblasts, which are essential for bone formation[(2)]. Preclinical and clinical studies have explored their use in the repair of nonunion fractures, with encouraging results indicating improvements in bone healing and functional recovery of patients. This integrative review aims to synthesize and critically analyze the available evidence on the treatment of pseudarthrosis with stem cells, covering everything from the biological mechanisms to the clinical and economic outcomes associated with this innovative approach[(3)].

In addition to the biological and clinical aspects, economic considerations are also crucial in the evaluation of new therapies. With the increasing costs associated with the management of postoperative complications and the need for surgical revisions, strategies that promote effective bone healing and reduce recovery time are of particular interest. Therefore, this review will not only examine the efficacy and

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safety of stem cells in pseudarthrosis, but also assess their potential economic impact when compared with conventional approaches[4].

A comprehensive understanding of the mechanisms by which stem cells promote bone healing is essential to support their clinical application. Investigations into the local microenvironment of the lesion, growth factors involved, and cellular interactions are fundamental to optimize treatment protocols. This review will seek to highlight not only the advances achieved to date, but also identify knowledge gaps that may guide future research and the refinement of stem cell therapeutic strategies in the management of pseudarthrosis[5].

Methods

The methodology adopted in this integrative review follows a systematic approach to synthesize and critically analyze the available literature on pseudarthrosis treatment using stem cells. Articles were searched in electronic databases, including PubMed, Scopus, and Web of Science, using search terms such as "pseudoarthrosis," "nonunion," "stem cells," "cell therapy," "bone healing," among other relevant terms. The search strategy was designed to identify studies that investigated the use of stem cells in pseudarthrosis models, covering both preclinical and clinical studies.

Inclusion criteria were established to select studies published in English, Spanish, or Portuguese that directly investigated the application of stem cells in the treatment of pseudarthrosis. Original articles, systematic reviews, and meta-analyses that reported results of clinical, radiological, and/or histological outcomes related to bone healing were considered. There were no restrictions regarding the year of publication, as long as the studies met the established inclusion criteria.

Initial screening of studies was performed based on titles and abstracts, followed by full reading of selected articles to determine their relevance and methodological quality. Extracted data included information on study characteristics (such as design, sample size, method of stem cell intervention), main outcomes (such as bone healing rate, incidence of complications), and authors' conclusions.

The methodological quality of included studies was assessed using appropriate tools, such as the Jadad scale for randomized clinical trials and the Risk of Bias in Non-randomized Studies – of Interventions (ROBINS-I) tool for observational studies. This approach allowed a critical analysis of the available evidence, considering potential biases and limitations of included studies.

Finally, data were synthesized in a narrative manner, as appropriate, to provide a comprehensive overview of findings and emerging trends in the field of stem cell treatment of pseudarthrosis. This integrative review aims to contribute to the updated understanding and guidance of future research and clinical practice in this promising area of regenerative medicine.

Results

The results of this integrative review indicate that the treatment of pseudarthrosis using stem cells shows promising results in terms of promoting bone healing. Preclinical studies have consistently demonstrated that, when applied in experimental models of pseudarthrosis, stem cells facilitate the formation of functionally integrated bone tissue[6]. Proposed mechanisms include the ability of stem cells to secrete growth factors and cytokines that stimulate osteogenic differentiation and promote local vascularization, essential for the healing process[7].

In clinical terms, observational studies and early clinical trials suggest that the use of stem cells may result in increased rates of successful bone healing compared to conventional approaches[8]. Patients undergoing stem cell therapies often presented better functional outcomes and a lower incidence of postoperative complications related to nonunion, such as infections or the need for surgical revisions[9].

Additionally, preliminary economic analyses indicate that despite the potential higher initial costs associated with the use of stem cells, long-term benefits may be observed due to reduced postoperative complications and shorter recovery times, resulting in potential savings in the health system[10].

It is important to emphasize that, although the results are encouraging, the heterogeneity in treatment protocols, types of stem cells used, and evaluation criteria among reviewed studies limits the generalizability of findings[11]. Furthermore, the variable methodological quality of included studies suggests the need for well-designed randomized clinical trials and long-term follow-up studies to corroborate these preliminary results[12].

Discussion

The discussion of findings of this integrative review highlights the promising efficacy of stem cells in the treatment of pseudarthrosis, reflected in favorable bone healing outcomes observed in preclinical and clinical studies[13]. The biological mechanisms proposed for this effect include the ability of stem cells to promote osteogenic differentiation and secrete growth factors that stimulate tissue repair[14]. These key aspects suggest that stem cells not only facilitate bone healing but may also positively influence the quality of the tissue formed, potentially reducing the risk of refractures and improving the functional integration of the recovered bone[15].

Although reviewed studies consistently demonstrate encouraging results, it is crucial to recognize the limitations and challenges faced in the clinical application of stem cells in the treatment of pseudarthrosis[16]. Heterogeneity in treatment protocols, including variations in the type of stem cells used, cell origin, administration methods, and outcome assessment criteria, makes direct comparison between studies and generalization of results difficult[17]. Furthermore, the variable methodological quality of the included studies highlights the need for well-controlled prospective studies to more robustly validate the observed findings[18].

Economic aspects are also relevant in evaluating the use of stem cells in the context of pseudarthrosis[19]. Although initial costs may be high due to the procedures required for collecting, processing, and applying the stem cells, potential benefits include short postoperative recovery time, low rates of complications related to nonunion, and, consequently, long-term savings in the health system[20].

Future perspectives include the need for further investigations to optimize stem cell treatment protocols, explore new, more accessible and sustainable sources of stem cells, such as mesenchymal stem cells derived from adipose tissue or bone marrow, and expand the understanding of molecular mechanisms underlying the efficacy of stem cells in pseudarthrosis[21]. In addition, long-term follow-up studies are essential to assess the durability of results and potential long-term adverse effects associated with the use of these emerging therapies[22].

In summary, despite the challenges and open questions, this integrative review highlights the transformative potential of stem cells in the treatment of pseudarthrosis, offering a new perspective in the approach to this complex and challenging orthopedic condition[19-21].

Conclusion

In conclusion, this integrative review highlights that the treatment of pseudarthrosis using stem cells represents a promising and innovative area of research in orthopedics and regenerative medicine. Results consistently indicate that stem cells have the potential to promote effective bone healing, reducing postoperative complications and improving functional outcomes for patients. The ability of stem cells to stimulate osteogenic differentiation and secrete growth factors that facilitate bone healing offers a viable alternative to traditional approaches, which are often limited by variable success rates and the risk of complications.

However, it is essential to recognize current limitations, including heterogeneity in treatment protocols and the variable quality of reviewed studies. The lack of standardization in methods for collecting, processing, and administering stem cells, together with the need for well-controlled randomized clinical trials, highlights the importance of future investigations to more robustly validate the therapeutic benefits of stem cells in pseudarthrosis. Economic aspects should also be considered in the clinical implementation of these therapies, with potential to optimize long-term costs by reducing complications and recovery time. In addition, advances in understanding the molecular mechanisms underlying stem cell efficacy and the identification of more accessible and sustainable cell sources may further expand the clinical impact of these interventions.

Given the encouraging results and identified challenges, the application of stem cells in the treatment of pseudarthrosis represents a new frontier in orthopedics and may significantly transform clinical management and health outcomes for patients with this debilitating condition. Continued research and improvement of clinical practices are essential to maximize the clinical and economic benefits of these emerging therapies in the field of orthopedic regenerative medicine.

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Review

Innovative approaches in the treatment of foot and ankle injuries

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Abstract

The treatment of foot and ankle injuries has evolved significantly with the introduction of innovative approaches aimed at improving clinical outcomes and patient recovery. This narrative review explores four key areas of innovation: regenerative therapies with stem cells and growth factors, minimally invasive surgery techniques, 3-dimensional (3D) printing and custom biomaterials, and the use of digital technologies and remote monitoring. Regenerative therapies have shown the potential to promote tissue regeneration and accelerate recovery, while minimally invasive surgery, such as arthroscopy, reduces invasiveness and recovery time. 3D printing and custom biomaterials offer solutions tailored to patients' anatomy, improving functionality and comfort. Digital technologies and remote monitoring facilitate continuous monitoring and treatment adherence. Despite advances, the clinical implementation of these innovations faces challenges related to cost, regulation, and equity of access. Integrating these approaches could significantly transform foot and ankle injury management, improving treatment effectiveness and patients' quality of life.

Level of Evidence III; Therapeutic Studies; Systematic Review of Level III Studies.

Keywords: Regenerative therapies; Minimally invasive surgery; Digital technologies.

Introduction

Foot and ankle injuries are prevalent in clinical practice, significantly impacting patients' mobility and quality of life. The causes of these injuries vary widely, from acute trauma to chronic degenerative processes such as fractures, sprains, tendinopathies, and ligament injuries. Historically, treating these conditions involved conventional methods such as immobilization, physical therapy, and, in some cases, surgical intervention. However, new approaches have emerged with medical science and technological advancement to optimize recovery, reduce rehabilitation time, and improve long-term functional outcomes[(1)].

In recent years, the introduction of regenerative therapies, such as stem cells and growth factors, has shown promising results in repairing soft tissue injuries and accelerating bone healing. In addition, minimally invasive techniques, such as arthroscopy, provide a less traumatic alternative to surgical interventions, reducing the morbidity associated with traditional procedures. These innovations and the developing of more biocompatible biomaterials and prostheses offer new perspectives for treating complex foot and ankle injuries[(2)].

Another area of significant advancement is using 3-dimensional (3D) printing technologies to create custom orthotics and prosthetics. These devices allow precise patient anatomy adjustment, improving comfort and treatment effectiveness. In addition, advances in digital technology-based rehabilitation, such as mobile apps and motion monitoring devices, are transforming how patients manage their recovery by offering real-time feedback and personalized exercise programs[(3)].

Treating these injuries also benefits from the increasing integration of personalized medicine and data analysis. Using artificial intelligence algorithms to predict the prognosis of injuries and customize treatment plans can revolutionize the clinical management of these conditions, providing more effective interventions with lower rates of complications. This multidisciplinary, patient-centered approach highlights the importance of combining emerging technologies with traditional clinical knowledge to achieve better outcomes[(4)].

Study perfomed at the Hospital Manoel Victorino, Salvador, Bahia, Brazil.

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The objective of this narrative review is to explore innovative approaches in the treatment of foot and ankle injuries, discussing emerging therapies and their impacts on current clinical practice. In addition, evaluate the evidence on the effectiveness of these new technologies compared to traditional procedures, highlighting the main advantages and challenges in their implementation.

Methods

A structured methodological protocol was followed to conduct this narrative review to ensure the analyzed sources' scope and relevance. Initially, a systematic search was performed in the main academic databases, including PubMed, Scopus, Web of Science, and Cochrane Library. Study selection was guided by specific inclusion and exclusion criteria, ensuring that only studies published between 2010 and 2023 were considered, focusing on innovative approaches in the treatment of foot and ankle injuries.

Descriptors used in the search included "foot injuries," "ankle injuries," "innovative treatment," "stem cells," "regenerative therapy," "biomaterials," "arthroscopy," "3D printing," and "digital technologies." The terms were combined using Boolean operators (AND, OR) to maximize the relevance of the results. Review articles, clinical trials, case studies, and meta-analyses were included as long as they directly addressed therapeutic innovations applicable to foot and ankle injuries.

After identifying the studies, titles and abstracts were screened to exclude duplicate publications and those not directly related to the proposed theme. The full texts of the selected studies were thoroughly reviewed, including those that presented detailed descriptions of the new therapeutic approaches and data on the effectiveness and safety of the proposed treatments.

Data extracted from the studies included information on the types of injuries treated, the innovative technologies or techniques applied, the clinical outcomes observed, and the limitations reported by the authors. The results were synthesized qualitatively, allowing the comparison of the different innovative therapeutic methods and their clinical applicability. Data analysis sought to identify emerging trends, implementation challenges, and potential areas for future research.

This narrative review was structured to provide critical insight into the current state of innovations in treating foot and ankle injuries, highlighting the promises and limitations of new technologies. Given the exploratory nature of this review and the diversity of interventions addressed in the selected studies, there was no quantitative evaluation or meta-analysis of the data.

Regenerative therapies with stem cells and growth factors

Regenerative therapies, particularly stem cells and growth factors, have emerged as an innovative approach in the treatment of foot and ankle injuries, offering a promising alternative to conventional methods. Mesenchymal stem cells, derived mainly from bone marrow or adipose tissue, can differentiate into several cell types, including osteoblasts, chondroblasts, and fibroblasts, contributing directly to the regeneration of damaged tissues. Recent studies indicate that these cells, when applied to ligament and tendon injuries, promote an acceleration in the healing process, improve the quality of tissue regeneration, and reduce the recovery time of patients[5].

In addition to stem cells, growth factors such as platelet-rich plasma (PRP) have been widely studied for their potential to modulate the inflammatory response and promote angiogenesis and tissue repair. Platelet-rich plasma, rich in bioactive factors such as platelet-derived growth factor (PDGF) and vascular endothelial growth factor (VEGF), is applied directly to injured areas, stimulating tendon and cartilage regeneration. In clinical trials, the use of PRP has shown encouraging results, with reduced pain and improved function in patients with chronic Achilles tendon injuries and plantar fasciitis[6].

However, despite promising results, data on the long-term effectiveness of regenerative therapies are still limited. Studies indicate significant variability in clinical outcomes depending on stem cell origin, PRP concentrations used, and the type of injury treated. This heterogeneity makes it difficult to standardize therapeutic protocols, which constitutes an obstacle to their wide adoption in clinical practice. In addition, although the safety of these therapies has been widely demonstrated, there are concerns regarding the strict control of the source and manipulation of cells and the possibility of adverse immune responses in some patients[5].

Another relevant aspect addressed in this review is the economic feasibility of these therapies. The costs of obtaining and processing stem cells and PRP are considerable, limiting access to these innovative treatments, especially in public health systems and less developed regions. In addition, the lack of clear reimbursements by insurers and regulations defined in several countries makes it difficult to include them in therapeutic routines[6].

Although regenerative therapies with stem cells and growth factors have great potential in treating foot and ankle injuries, there are still substantial challenges related to the standardization of protocols, cost, and accessibility. Continuing research is essential to optimize these approaches and establish their position in clinical practice, especially with long-term studies that can validate their efficacy in different types of injuries and patient populations[5].

Advances in minimally invasive surgery: arthroscopy and percutaneous techniques

Minimally invasive surgical techniques, such as arthroscopy and percutaneous procedures, have revolutionized the treatment of foot and ankle injuries, providing significant benefits over traditional surgical procedures. Arthroscopy, which allows access to the interior of the joints through small incisions, has stood out in the management of ligament injuries, tendinopathies, and intra-articular fractures. Compared to open surgeries, the reviewed studies indicate that arthroscopy offers faster recovery, less postoperative pain, and a lower risk of complications such as infections and extensive scarring[7].

Advances in arthroscopic techniques, such as high-definition cameras and articulated instruments, have allowed greater surgical precision and less tissue trauma. In specific injuries, such as severe ankle sprains and Achilles tendon ruptures, arthroscopy is effective in restoring joint stability and biomechanical function, with high success and low complication rates. Studies included in this review indicate that this approach improves immediate functional results and reduces the time to return to sports and occupational activities, which is especially relevant for athletes and individuals with high physical demands[8].

In addition to arthroscopy, percutaneous techniques have emerged as a minimally invasive alternative in the treatment of foot and ankle fractures and deformities. Procedures such as percutaneous osteosynthesis of calcaneal fractures and correction of hallux valgus deformities are effective in reducing surgical time and morbidity associated with open incisions. This review highlights that these techniques, when applied to indicated injuries, can reduce the risk of complications, such as skin necrosis and infection while preserving adjacent anatomical structures[9].

However, it is important to note that the effectiveness of these techniques is directly related to the surgeons' learning curve. This review suggests that while arthroscopy and percutaneous techniques offer better outcomes for patients, inadequate execution due to a lack of specialized training can result in complications such as neurovascular lesions and bone fixation failures. Therefore, there is a continuing need for training and enhancing the skills of surgeons and the development of clinical guidelines that guide the proper selection of patients for these interventions[8].

Another point discussed in our review is the limited access to these technologies in less developed regions or health systems with limited resources. Although minimally invasive techniques provide clear advantages, the high cost of equipment and the need for specialized infrastructure may restrict their wide adoption. Future studies should focus on strategies to make these technologies more accessible and evaluate their effectiveness in diverse clinical settings and populations with different risk profiles[9].

Advances in arthroscopy and percutaneous techniques represent a milestone in the treatment of foot and ankle injuries, providing better functional recovery, less surgical trauma, and reduced complications. However, the full implementation of these techniques depends on specialized training, access to technological resources, and continuous development of studies that validate their effectiveness in the long term and different populations[8].

3D printing and custom biomaterials

The application of 3D printing and the development of customized biomaterials represent significant innovations in treating foot and ankle injuries, offering tailored solutions that improve the accuracy and effectiveness of therapeutic interventions. 3D printing technology has created customized prostheses, orthoses, and implants tailored to each patient's anatomy. This approach allows for more precise adaptation to the injury site, resulting in better stability and functionality than traditional methods using standardized devices[10].

Recent studies indicate that the customization of orthoses and prostheses using 3D printing has demonstrated clear benefits in patient comfort, reduction of postoperative complications, and optimization of clinical outcomes. In complex fractures or congenital deformities, personalized implants offer a more faithful anatomical reconstruction, contributing to a faster and more efficient functional recovery. In addition, 3D printing facilitates the fabrication of anatomical models for surgical planning, allowing surgeons to visualize and simulate the procedure before the intervention, increasing accuracy and reducing intraoperative time[11].

Biomaterials used in 3D printing have also evolved, incorporating biocompatible materials that promote integration with surrounding tissues and minimize the risk of rejection. Using biodegradable polymers and composite materials such as ceramics and metals offers versatile options for creating temporary or permanent devices depending on clinical need. These materials are designed to withstand the biomechanical forces associated with the foot and ankle while favoring bone and tissue regeneration. However, our review points out that there are still technical challenges, such as optimizing the mechanical strength of these materials to ensure the longevity of implants in patients with high functional demand[12].

Despite the demonstrated benefits, the high cost associated with 3D printing and the development of customized biomaterials remains an obstacle to their large-scale implementation. Our review highlights that the production of these devices still requires specialized equipment and manufacturing processes that drive up costs, making them inaccessible for many patients, especially in public health systems. In addition, the lack of standardized regulation for the clinical use of 3D-printed implants raises questions about their long-term safety and effectiveness, and further studies are needed to validate these devices in large clinical trials[10].

Additionally, our review points out that 3D printing in clinical settings still faces limitations related to production time. While the technology allows for the creation highly customized devices, the time required to design, test, and produce a customized implant or orthosis may not be feasible in emergencies or when immediate surgical interventions are required. Therefore, developing faster and more efficient production processes is fundamental to expanding the clinical use of these technologies[11].

3D printing and custom biomaterials can potentially transform the treatment of foot and ankle injuries by offering tailored solutions that improve anatomical adaptation, reduce complications, and increase treatment effectiveness. However, the wide implementation of these approaches requires overcoming barriers related to cost, regulation, and production time and continuous studies to ensure their safety and effectiveness in the long term[12].

Use of digital technologies and remote monitoring in rehabilitation

Digital technologies and remote monitoring transform foot and ankle injury rehabilitation, providing more efficient, personalized, and affordable approaches. Mobile apps, wearable devices, and telemedicine platforms have been increasingly used to monitor patient progress, optimize rehabilitation programs, and facilitate communication between healthcare providers and patients. This review highlights that these digital tools offer a practical form of continuous follow-up, allowing real-time adjustments in treatment based on patient performance, which enhances recovery and improves treatment adherence[13].

One of the main benefits of using digital technologies in rehabilitation is the ability to monitor biomechanical parameters, such as weight load, range of motion, and muscle strength, through sensors coupled to wearable devices, such as smart orthoses and adaptive footwear. These devices provide real-time data, allowing healthcare professionals to fine-tune the rehabilitation program accurately and based on evidence. Reviewed studies indicate that this approach can reduce recovery time and improve functional outcomes while decreasing the need for in-person visits, which is particularly useful for patients with walking difficulties or living in remote areas[14].

In addition, mobile applications have played a key role in encouraging patients to adhere to rehabilitation protocols. Digital platforms that offer guided exercise videos, reminders, and real-time feedback increase patient motivation and ensure that exercises are performed correctly. Our review suggests that using these apps significantly improves patients' engagement with treatment, resulting in faster and more efficient recovery. However, the variability in the quality and accuracy of the applications available in the market is a challenge, and this review recommends the development of regulations that guarantee the effectiveness and safety of these tools[15].

Another relevant aspect addressed in our review is the positive impact of telemedicine on the follow-up of patients with foot and ankle injuries. Virtual consultations allow health professionals to monitor rehabilitation progress and make adjustments to treatment without the need for frequent face-to-face consultations. In addition, remote monitoring provides a more integrated multidisciplinary approach, allowing collaboration between specialists, such as physiotherapists, orthopedists, and rheumatologists, resulting in a more cohesive and individualized treatment plan. However, our review indicates that a lack of adequate infrastructure and limited internet access in some regions may hinder large-scale implementation[13].

Despite the benefits, the widespread adoption of digital technologies and remote monitoring in foot and ankle injury rehabilitation still face significant challenges. Issues related to data privacy, cybersecurity, and integration with existing health systems are important concerns that must be addressed. This review also suggests that while digital technologies have shown promising results, the lack of long-term studies on the clinical effectiveness of these approaches limits their wider acceptance among healthcare professionals[15].

The use of digital technologies and remote monitoring in the rehabilitation of foot and ankle injuries offers new opportunities to improve the effectiveness and efficiency of treatment, providing greater accessibility and personalization of care. However, for these approaches to be widely implemented, it is necessary to overcome technical, regulatory, and infrastructure barriers and conduct further studies that validate their long-term benefits in different populations[14].

Future perspectives and challenges in the clinical implementation of innovative approaches

Innovative approaches in the treatment of foot and ankle injuries, such as using regenerative therapies, personalized biomaterials, minimally invasive techniques, and digital technologies, present significant potential to transform the management of these conditions. However, widespread clinical implementation of these technologies still faces substantial challenges. Prospects indicate that as new technologies are improved and become more accessible, there will be an improvement in functional patient outcomes and an acceleration in recovery times. However, integrating these innovations into clinical practice requires a careful approach that considers economic viability, access equity, and patient safety[16].

One of the main challenges in adopting these approaches is the technological infrastructure and the associated costs. For example, 3D printing, custom biomaterials, and stem cell therapies are still high-cost technologies, limiting their availability in public health systems and regions with fewer resources. Studies indicate that reducing production costs and developing standardized protocols are crucial to disseminating these innovations. Prospects, therefore, should focus on developing strategies to make these technologies more accessible, including partnerships between research institutions and medical technology industries, as well as government investments to facilitate their adoption[17].

In addition to economic challenges, education and training of health professionals are determining factors for the successful implementation of these new approaches. Minimally invasive surgical techniques, such as arthroscopy and percutaneous procedures, require specialized skills and continuous training. Our review highlights that many surgeons still face a significant learning curve when adopting these techniques, which can limit their application and increase the risk of complications. In the future, medical education programs must include specific training for using these technologies, ensuring that professionals can apply them safely and effectively[18].

Another crucial point is the regulation and scientific validation of these new approaches. Although regenerative therapies, such as stem cells, have shown promising results in early preclinical and clinical studies, the lack of robust long-term data still precludes their large-scale adoption. Our review points out that, without clear guidelines and more robust clinical evidence, hesitancy to adopt these technologies persists among many health professionals. Future progress will depend on large-scale and long-term clinical trials proving the safety and efficacy of these therapies and formulating regulations that guide their clinical application[19].

Equity in access to innovations also stands out as an important challenge. Digital technologies such as remote monitoring devices and mobile applications can significantly benefit the rehabilitation of patients with foot and ankle injuries. However, our review points out that access to these technologies is still uneven, especially in rural areas and countries with less technological development. In the future, expanding internet access and digital inclusion will be key to ensuring that these tools can benefit a larger portion of the population. In addition, health systems need to adopt policies that promote the use of these innovations in an inclusive manner[20].

Prospects for treating foot and ankle injuries are promising, with the potential to significantly improve clinical outcomes by adopting innovative approaches. However, the challenges to its implementation include cost, infrastructure, professional training, regulation, and equity of access. Overcoming these obstacles will require a collaborative approach between governments, research institutions, and industry and ongoing efforts to validate and standardize these new technologies in the clinical setting[16].

Conclusions

Regenerative therapies, minimally invasive surgical techniques, personalized biomaterials, digital technologies, and remote monitoring emerge as promising solutions to overcome the limitations of traditional treatments. The ability of these interventions to offer greater precision, personalization, and ongoing follow-up has the potential to transform clinical practice, providing more efficient recovery and a better quality of life for patients.

However, the widespread implementation of these innovations still faces substantial challenges, such as high costs, the need for adequate technological infrastructure, ongoing training of healthcare professionals, and stringent regulation to ensure the safety and effectiveness of new approaches. In addition, equity in access to these technologies remains a significant barrier, especially in health systems with limited resources. In the future, joint efforts among researchers, healthcare professionals, managers, and the medical technology industry will be essential to make these innovations accessible and effectively integrate them into clinical practice.

In short, although technological innovations in treating foot and ankle injuries are at an advanced stage of development and implementation in some contexts, the full realization of their potential will depend on overcoming economic, technical, and social barriers. With the continuous advancement of research and the democratization of access to these technologies, managing these injuries is expected to be increasingly effective, substantially improving clinical outcomes and patient experience soon.

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Original Article

A modified method for measuring the calcaneal moment arm on weight-bearing computed tomography

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Abstract

Objective: This study introduced a modified weight-bearing computed tomography to measure the calcaneal moment arm (WBCT-CMA) and compared the CMA values between the original and modified techniques.

Methods: The WBCT scans of 10 healthy feet were loaded in the CubeVue software, correctly oriented in the transverse plane. Instead of using a specific single coronal cut of the tibia, as in the original WBCT-CMA method, the modified method includes the full thickness of the tibia in the coronal plane to better define the tibia axis. The CMA of each foot was evaluated using both methods. Intraclass correlation coefficient (ICC) model was used to assess the intra- and interobserver reliabilities of both techniques.

Results: There was no statistically significant difference between the CMA values generated from the two measurement techniques ($p = 0.99$). Both methods demonstrated excellent intra- and interobserver reliabilities (0.93 and 0.97 for the modified WBCT-CMA, and 0.93 and 0.94 for the original WBCT-CMA).

Conclusion: The modified WBCT-CMA is equivalent to the original WBCT-CMA in both intra- and interobserver reliabilities. Instead of using a relatively shorter tibia from one specific single cut, as in the original technique, the modified WBCT-CMA provides a reconstructed tibia with a longer and clearer shaft for measurement. This has the potential advantages of being easy to perform and less time-consuming, also reducing errors.

Level of Evidence III; Retrospective comparative study.

Keywords: Weight-bearing; Joint instability; Orthopedic procedures; Tomography, x-ray computed.

Introduction

In 1976, Cobey[1] introduced the posterior roentgenogram of the foot, a two-dimensional method for radiographically imaging the leg and heel in the coronal plane. This innovation made direct evaluation of the hindfoot alignment on X-rays possible. In 1995, Saltzman and El-Khoury[2] introduced the hindfoot alignment view and the parameter of apparent moment arm, which was quickly accepted and popularized as one of the main measurements of the hindfoot alignment.

In 2012, weight-bearing computed tomography (WBCT) was introduced to the field of foot and ankle[3]. This technology captures three-dimensional images whilst the patient is fully weightbearing. It has the advantages of overcoming the overlap of structures that is inevitable in the x-ray path, reducing operator-related bias[4], diminishing projection bias, and overall better demonstrating the geometry and health status of bones and joints in the foot[5] when compared to two-dimensional X-rays. It also better demonstrates the alignments of bones and joints in their biomechanical weight-bearing status when compared to traditional non-weight-bearing CT scans[6]. Therefore, WBCT is gaining more and more recognition and usage in evaluating the hindfoot alignment, as a strong addition to the traditional two-dimensional X-ray.

Study performed at the University of Colorado School of Medicine, Aurora, Colorado, United States.

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In 2021, Arena et al.[7] introduced the new technique for measuring the calcaneal moment arm (CMA) on WBCT scans (WBCT-CMA). However, the authors of this study have found that the WBCT-CMA technique leaves room for further inquiry in perspectives of accuracy, thoroughness, and ease of use.

The goal of this study was to modify the WBCT-CMA method into a new version, which was therefore called the modified WBCT-CMA, and compare the intra- and interobserver reliabilities between the modified and original WBCT-CMA techniques.

Methods

Subjects

This was a retrospective study using WBCT scans captured as part of routine clinical care. The study was conducted with institutional review board approval. Inclusion criteria were feet without remarkable foot and ankle deformities. The WBCT scans of 10 feet without remarkable deformities were used, with five scans from each laterality. Eight scans were from males (80%) and two scans were from females (20%). The age of subjects ranged from 22 to 51 years, with an average age of 35 years (SD = 11.18 years).

Measurement methods and data collection

The main difference between the modified WBCT-CMA and the original WBCT-CMA is that, instead of using a specific single coronal cut of the tibia as described in the original method, the modified method includes the full width and length of the tibia in the coronal plane to better and easier define the tibia axis[8].

All WBCT scans were imported into the CubeVue software (CurveBeam LLC, USA). The foot was first aligned in the transverse plane to a neutral 0° position in terms of internal and external rotation, based on the long axis going through the second metatarsal head and posterior base of the heel. Then, the calcaneus weight-bearing point was determined, as corroborated in the sagittal, coronal, and transverse planes. In the sagittal plane, thickness of one scan slice was increased to include the full width and length of the tibia in the coronal view, being careful as to not let the fibula occlude the lateral cortex of the tibia (Figure 1). By doing this, a reconstructed view of the full tibia in the coronal plane was obtained. In this view, two circles were drawn, with the distal circle tangent to the tibia plafond and both the medial and lateral cortexes of the distal tibia, while the proximal circle is in the most proximal aspect of the tibia, tangent to both the medial and lateral cortexes of the proximal tibia. The bisecting line connecting the midpoints of both circles and extending distally to the weight-bearing surface was used as the axis of the tibia. The calcaneus weight-bearing point was relocated in the coronal view using the intersection of axial lines. A line parallel to the ground was drawn between the calcaneus weight-bearing point and the extension of the tibial axis to measure the modified WBCT-CMA in the coronal view. When the weight-bearing point of the calcaneus fell on the medial side of the tibial axis, a negative modified WBCT-CMA value was recorded, indicating a varus hindfoot alignment; when the weight-bearing point of the calcaneus fell on the lateral side of the tibial axis, a positive modified WBCT-CMA value was recorded, indicating a valgus hindfoot alignment. Each value was measured twice by two independent observers.

Statistical analysis

An intraclass correlation coefficient (ICC) model was used to assess the intra- and interobserver reliability of CMA values (Table 1). The ICC values were interpreted as follows: less than 0.50, representing poor reliability; between 0.5 and 0.75, representing moderate reliability; between 0.75 and 0.9, representing good reliability; and greater than 0.90, representing excellent reliability[8]. A paired t-test was used to compare the average difference between the modified WBCT-CMA and original WBCT-CMA values. Statistical analysis was completed using the EXCEL and SAS software. A p value <0.05 was considered to indicate statistical significance.

Figure 1. In the original WBCT-CMA technique (top), the tibia axis is determined only in one specific coronal cut, denoted by the slice that has "the widest tibial diaphyseal distance at the most proximal edge of the image"[7] (top left). Alternatively, in the modified WBCT-CMA technique (below), the tibia axis is drawn on a reconstructed coronal view involving the full length and width of the tibia.

Results

There was no statistically significant difference in both intra- and interobserver reliabilities between the modified WBCT-CMA and original WBCT-CMA techniques. Both methods demonstrated excellent intra- and interobserver reliabilities (0.93 and 0.97 for the modified WBCT-CMA technique, and 0.93 and 0.94 for the original WBCT-CMA method). There was also no statistical difference between the CMA values generated using the two measurement techniques (average difference between both methods was 0.003 mm, $p = 0.99$).

Table 1. Intra- and interobserver reliability of both CMA measurements

	ICC	SD	95% CI	
			Lower	Upper
Overall				
Interobserver	0.93	0.02	0.87	0.96
Intraobserver	0.95	0.02	0.91	0.98
Original WBCT-CMA				
Interobserver	0.93	0.03	0.84	0.97
Intraobserver	0.94	0.03	0.85	0.97
Modified WBCT-CMA				
Interobserver	0.93	0.03	0.84	0.97
Intraobserver	0.97	0.02	0.93	0.99

ICC: Intraclass correlation coefficient; SD: Standard deviation; CI: Confidence interval; WBCT-CMA: Weight-bearing computed tomography to measure the calcaneal moment arm

Discussion

Hindfoot malalignment can lead to pain, disability, and joint degeneration[9]. The accuracy and precision in evaluating the hindfoot alignment is critical to clinical practice. This study introduced a modified WBCT-CMA method with the goal of increasing the accuracy and ease of use of the measurement.

Mainly, the modified WBCT-CMA differs from the original WBCT-CMA in the way how the tibia axis is established. In the original WBCT-CMA, the tibia axis is drawn in a single coronal slice which has the "widest tibial diaphyseal distance at the most proximal edge of the image." However, this methodology could be easily biased by interpretation, human error, and radiographic inadequacy. For example, one observer may determine slice "A" has the widest proximal tibial diaphyseal distance, while another observer may identify an entirely different cut slice "B," millimeters away. Furthermore, a single coronal cut based purely on the proximal edge of the image may be compromised by radiographic inadequacy, an incomplete view, or an image that does not capture detailed architecture. Most importantly, as demonstrated in Figure 2, the cut with the "widest tibial diaphyseal distance at the most proximal edge of the image" chosen for drawing the proximal circle in the original WBCT-CMA technique does not guarantee inclusion of the tibial plafond for placing the distal circle. Likewise, the cut including the whole tibial plafond may not be the one with the "widest tibial diaphyseal distance at the most proximal edge of the image." In essence, the "single cut" window is too restrictive to allow including the maximal

Figure 2. At the widest tibial diaphyseal distance at the most proximal edge of the image, the first image demonstrates how the tibia plafond may not be in view, whilst the third image (following the WBCT-CMA method[7]) demonstrates a cut where the tibia plafond was in view. With the distal tibial plafond secured, the middle image demonstrates how the most proximal edge of the image is poorly defined, thus the proximal circle had to be placed more distally to adequately capture the edges of the tibia.

width of the tibia both proximally and distally. To address the aforementioned issues, the modified WBCT-CMA method includes multiple coronal cuts and stacks them together to reconstruct the full coronal width of the tibia. Thus, there is no compromise in defining the tibia axis both proximally and distally. By doing so, it also increases the possibility of including more of the proximal tibia in view. A short tibial view might be deceiving in patients with deformity or other anatomic deviation in the proximal tibia, such as genu varum and genu valgum, or an anteriorly/posteriorly bowing tibia or leaning tibia due to dorsiflexion or plantarflexion of the ankle. Especially in the example of an anteriorly/posteriorly leaning tibia, the position of a single coronal slice drastically alters the resulting image, with the risk of capturing a truncated tibia (Figure 1). Incorporating the whole length of scanned tibia allows a measurement more proximal on the tibial diaphysis and, therefore, better reflects the long axis of the tibia. Moreover, the thicker coronal slice yielded more anatomic detail (Figure 1) and a greater view of the hindfoot and surrounding structures for the alignment assessment, particularly in legs with deformities. Improved anatomic detail provides clearer and sharper proximal aspects of the tibia and has the additional benefit of creating less difficulty in placing the proximal circle, also reducing the laborious task of finding the "one" specific cut for establishing the tibial axis.

Statistically speaking, both methods are equivalent. However, the modified method is more reliable in determining the view in which to measure the tibia axis. Thus, bias in selection is reduced, allowing for more robust measurements and the ease of duplicity.

The modified WBCT-CMA and the original WBCT-CMA have some common limitations. Firstly, how close the long axis generated from bisecting the tibia proximally and distally is to the real alignment of the tibia highly depends on how much of the tibia has been scanned. It may not reflect the natural curvature of the tibia and might lead to over- or underestimations of valgus or varus deformities. Secondly, the CubeVue software (version 3.9.195, CurveBeam LLC, 2021) only has the ellipse feature, without the function of drawing a perfect circle. This inevitably introduces human error. Thirdly, as for the anterior-posterior as well as medial-lateral correction that has been described above, rotation on the axial plane was not standardized in either method. Rotation of the foot during acquisition of axial radiographs or rotation of the axial WBCT image will significantly affect the outcome of hindfoot measurements. However, this was the topic of a paper recently published and was not the focus of this study[8].

Conclusion

In sum, the modified WBCT-CMA has equivalent intra- and interobserver reliability when compared to the original WBCT-CMA. In addition, it has the potential advantages of ease of use, less consumption of time, and reduced selection bias by including full thickness of the tibia in the coronal plane.

Authors' contributions: Each author contributed individually and significantly to the development of this article: SS *(https://orcid.org/0009-0008-7113-6032) Data collection, wrote the article; MZ *(https://orcid.org/0000-0002-9685-4048) Data collection, wrote the article); WG *(https://orcid.org/0000-0002-7342-7000) Data collection, survey of the medical records); CW *(https://orcid.org/0000-0003-2775-8252) Data collection, survey of the medical records); SS *(XXX) Data collection, survey of the medical records; KJH *(https://orcid.org/0000-0002-8369-8744) Conceived and planned the activities that led to the study, bibliographic review; MSM *(https://orcid.org/0000-0001-5124-2403) Conceived and planned the activities that led to the study, bibliographic review; SL *(https://orcid.org/0000-0003-1238-8455) Conceived and planned the activities that led to the study, bibliographic review. All authors read and approved the final manuscript.*ORCID (Open Researcher and Contributor ID iD.

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Original Article

Kinetics assessment of foot injury risk during vertical jump from varying heights in barefoot condition

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Abstract

Objective: Understand how certain kinetic variables change during vertical jumping from different heights in barefoot condition.

Methods: Twenty healthy, physically fit male and female adults were selected for the experiment. Mean age, height, and weight of male participants were 20.08 ± 1.230 years, 174 ± 1.071 cm, and 70.57 ± 3.002 kg; for female participants, mean age, height, and weight were 19.14 ± 1.027 years, 155 ± 0.048 cm, and 52.56 ± 5.461 kg, respectively. Experiments started with barefoot forefoot jumping from two different heights, 33 cm and 49 cm. Initial contact force (N), initial contact time (s), max force (N), max force time (s), stabilization force (N), time from max force to max force before stabilization (s), and time from max force to stabilization force (s) during jumps were measured using a Kistler portable force plate and studied in the MARS Quarter performance analysis software.

Results: Barefoot jumping data showed a scattered pattern for all selected parameters. Maximum force reached 3960.05 ± 2125.255 N at 33 cm and 4844.25 ± 2259.230 N at 49 cm. In a previous study, the average peak force measured was 4640 N. A 50% chance of fracture was linked to an impact of 3562 N, which is very close to the figure found in this study. Stabilization force reached 584.40 ± 106.308 N at 33 cm and 583.35 ± 99.881 N at 49 cm, with a correspondence of 0.56 ± 0.149 s and 0.66 ± 0.258 s, respectively. Minimum force achieved before stabilization was 341.0 N at 33 cm and 320.70 N at 49 cm. Regression analysis of these parameters showed a low R-squared value and a random fit plot.

Conclusion: According to our findings, jumping barefoot from a 49 cm height produces a higher impact on the forefoot than a 33 cm jump, except for initial contact and stabilization force. Before stabilization, the time from max force to max force before stabilization significantly affects stability during take-off, potentially preventing injury by allowing for a smoother transition between the eccentric (braking) and concentric (propulsion) phases. This data can help improve sports and kids' footwear to lower the risk of foot injuries.

Level of evidence IV; Economic and decision analyses – developing an economic or decision model.

Keywords: Foot Injuries; Disease prevention; Genes, jumping.

Introduction

The act of jumping, a fundamental human movement, has been studied extensively in various contexts. From leaping over obstacles to executing high-intensity athletic maneuvers, understanding the biomechanics of jumps is crucial for optimizing performance and minimizing injury risks[1-2]. Footwear greatly affects the jumping mechanics, but barefoot jumping provides a unique perspective on how the human body interacts with the ground. Interest in barefoot activities has grown due to insights into injury risks when not wearing footwear[3-4]. Some past literature suggests that going barefoot enhances interaction with the environment, improving balance and movement efficiency, but it also exposes individuals to specific risks, particularly during jumps, as landing from different heights is influenced by surface properties and the body biomechanics[5].

Jumping in sports and movement activities can lead to lower-limb musculoskeletal injuries in the hip, knee, and ankle. Factors contributing to these injuries include forces, body position at landing, movement execution, and landing

The study performed at the Centre of Excellence, Footwear Design and Development Institute (FDDI), Noida, India.

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surface. Recent studies aim to identify specific performance factors leading to these stresses[6]. It is reported that the jumping and landing biomechanics are closely related to the risk of acute injury due to prolonged exposure to high ground reaction forces (GRFs). Landing biomechanics is related to muscle control, muscle fatigue, flexibility, and musculoskeletal stiffness, but these multiple factors collectively represent the individual's landing technique, which has been considered one of the most important factors related to injury potential. The technique employed directly affects the capacity of joints to absorb the energy associated with the large-magnitude GRFs experienced upon ground contact[7].

Landing maneuvers are a fundamental task in high-risk sports activities such as volleyball, handball, and basketball[8]. The landing technique and the height may affect the GRF and lower limb kinematics[9]. Thus, poor landing mechanics with inadequate movement at the hip, knee, and ankle joints will not only reduce shock absorption but also increase the risk of lower limb injury[10-11]. During a walk, the vertical ground reaction force (v-GRF) is approximately 1.2 times the body weight. This value increases to 2.5 times the body weight while running and to 4 times the body weight while jumping. Therefore, repetitive jumping can lead to a microtrauma of muscles and, eventually, to sprains. The combination of height and jumping seems particularly important from a kinetic and kinematic perspective, reinforcing the idea that these factors, combined, are likely to increase the risk of ankle injury due to poor landing[12-13].

The purpose of this intense research is to bridge the gap in understanding barefoot jumps by focusing on kinetic responses across varying elevations. This study investigates initial contact force (N), max force (N), min force before stabilization (N), stabilization force (N), and time from max force to stabilization force (s) during descent. By dissecting these kinetic variables, our goal is to identify critical factors that contribute to injury risks and inform evidence-based strategies for injury prevention. Thu, this study aims to shed light on injury prevention strategies and improve performance based on the kinetic responses of barefoot jumping from different heights. Such barefoot data should set the standard value to be considered while developing and identifying the best footwear. To reduce the injury risk, this response delves into the design, integration, and development of footwear for various activities, including sports and children's footwear.

The hypothesis of this study's findings have practical implications for athletes, fitness enthusiasts, and kids engaging in barefoot activities. By elucidating kinetic responses during jumps, these results can tailor jump-specific exercises to optimize performance and reduce injury risks. Insights from barefoot jumps can set a mirror for the development of footwear that mimics natural biomechanics while providing the necessary protection. Whether hiking, parkour, or recreational sports, understanding the risks associated with different elevations empowers individuals to make informed choices.

Methods

The experimental protocol was screened and approved by the Ethics Committee (Ref. No. HMC/ IEC/ FDDI/ 01, dated 18th April 2024) in compliance with the Helsinki Protocol (1964-2013).

Selection of subject trials

This cross-sectional study aimed to collect barefoot jumping kinetic responses considering different heights. For this, 20 (n = 20; male: 13, female: 7) healthy, physically fit male and female adults who had no foot deformities or musculoskeletal abnormalities in the lower limbs and no history of musculoskeletal disorders or fractures on the lower extremity and vestibular system were selected for the final experiment. Mean age, height, and weight of male participants were 20.08 ± 1.230 years, 174 ± 1.071 cm, and 70.57 ± 3.002 kg, while for female participants mean age, height, and weight were 19.14 ± 1.027 years, 155 ± 0.048 cm, and 52.56 ± 5.461 kg, respectively. Experiments started with barefoot forefoot jumping from two different heights, 33 cm and 49 cm.

At least three trials of each subject and for each height condition were required, totaling 120 trials (20 x 3 x 2 = 120 trials). During data processing, the mean of all three trials of each condition was calculated as the final value. Five trials were excluded due to diversity, leaving us with 115 trials for the final experiment.

Before the study beginning, participants received all the necessary information and were informed about the study protocol; they also completed an informed consent form. Subjects had the freedom to withdraw their participation at any point during the experiment.

Experimental design of the study

Participants were previously informed about the procedures and their written consent was obtained. To get them accustomed to the study protocol, participants were asked to jump barefoot from two different heights, 33 cm and 49 cm. Before the study beginning, subjects were asked to comfortably jump from the selected heights and touch the force plates with their toe region. Then, they repeated this process three times for each condition, from the 33 cm height and from the 49 cm height. There was a 30-minute rest period between each trial of a selected height. Each experiment lasted five seconds, and data was collected and processed using the Kistler Quattro Jump (Model 9290DD, Kistler Instrumente AG, Switzerland) equipment and MARS Quarter (Type 2822A, Kistler Instrumente AG, Switzerland) performance analysis software.

Instrumentation

Quattro Jump comprises a portable Kistler force plate and the comprehensive Kistler MARS performance analysis software. The force plate measures the vertical force applied to assess a large variety of performance parameters. Quattro Jump objectively measures force, power, and jump height.

These force platforms are based on piezoelectric sensors. The MARS Quarter performance analysis software was used to collect and process data. Data was collected for each full jump in each experiment at a sampling rate of 25 Hz. The laboratory environment was maintained at an optimal temperature and humidity of 25 °C–27 °C and 50%–55%, respectively, at the Footwear Design and Development Institute (FDDI), in India.

Studied parameters

Initial contact force (N), initial contact time (s), max force (N), max force time (s), stabilization force (N), time from max force to max force before stabilization (s), and time from max force to stabilization force (s) during the barefoot forefoot jump from two different heights were obtained by using the MARS Quater performance analysis software.

Ethical clearance

Our study followed the principles outlined by the Declaration of Helsinki Protocol, 1964, and as per approved ethical clearance No HMC/ IEC/ FDDI/ 01, dated 18.04.2024.

Statistical analysis

Data were summarized into mean ± standard deviation (SD) values. Shapiro-Wilk normality test showed that parameters were not normally distributed. Thus, the Mann-Whitney *U* test was performed to compare the means of both heights' kinetic parameters. The significance level was defined as 0.05. Statistical software package SPSS-26 was used to analyze data.

Results

A scatterplot compared the initial contact force (N) with initial contact time (s); max force (N) with max force time (s); and stabilization force (N) with time from max force to max force before stabilization (s). Additionally, it included a radar chart of the stabilization force, a probability plot of time from max force to stabilization, and a line plot of time from max force to max force before stabilization. These data demonstrate the balance and stability dynamics of barefoot jumping.

The initial contact force (N) vs. initial contact time (s) scatterplot illustrates the relationship between the force applied during initial contact (e.g., stepping on a jump force plate) and the time it takes for that force to be applied. Points on the scatterplot form an upward-sloping pattern, indicating that a higher initial force tend to occur earlier in the movement.

The ability to stabilize (e.g. maintaining balance after a sudden force) is associated with the time it takes to regain stability after experiencing maximum force. To maintain balance and stability after jumping, there should be a negative correlation. The stabilization force radar chart displays different aspects of stabilization force, such as lateral and anterior-posterior stability. The shape of the radar chart gives an overall picture of stabilization force across these dimensions. The probability plot is used to assess the distribution of a variable – in this case, the time it takes from maximum force to stabilization. It helps determine if data follows a specific distribution. Deviations from a straight line indicate departures from the assumed distribution. The line plot shows how the time from maximum force to reaching another specific stabilization point changes over time. A sloping line indicates the rate of change, while a flat line suggests a constant time interval.

Figures 1 to 6 and Table 1 demonstrate the barefoot jumping dynamics and stability in two jumping heights, 33 cm and 49 cm. This data on dynamics represent the future design dimension achieving better balance and stability.

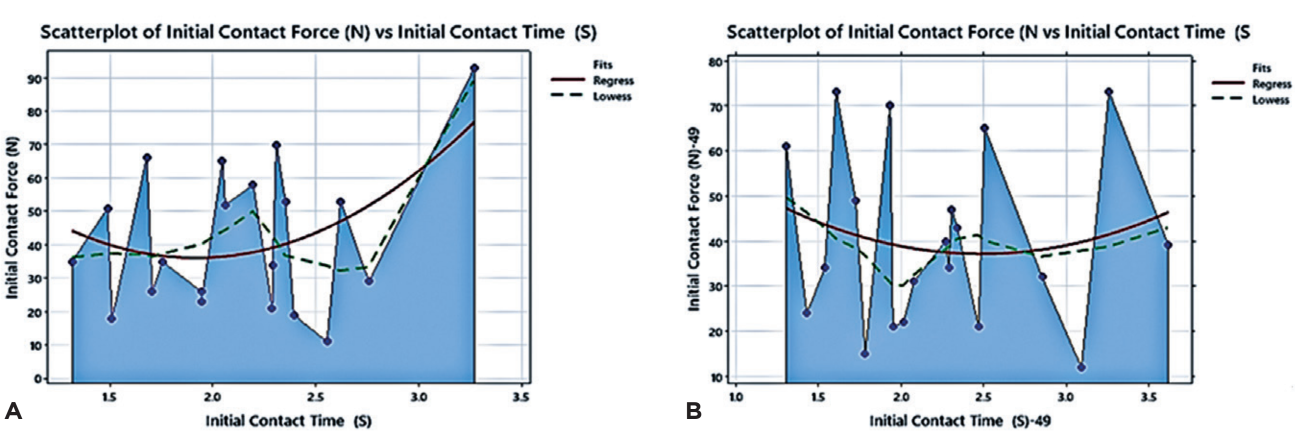

Figure 1. Scatterplot of initial contact force vs. initial contact time with Regress and LOWESS fit models for a 33 cm jump height (A) and a 49 cm jump height (B).

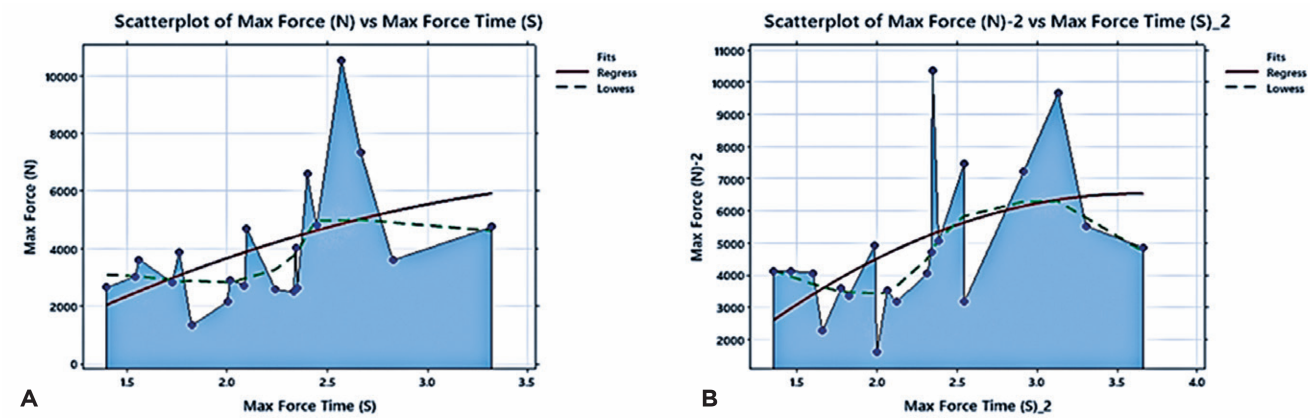

Figure 2. Scatterplot of max force vs. max force time with Regress and LOWESS fit models for a 33 cm jump height (A) and a 49 cm jump height (B).

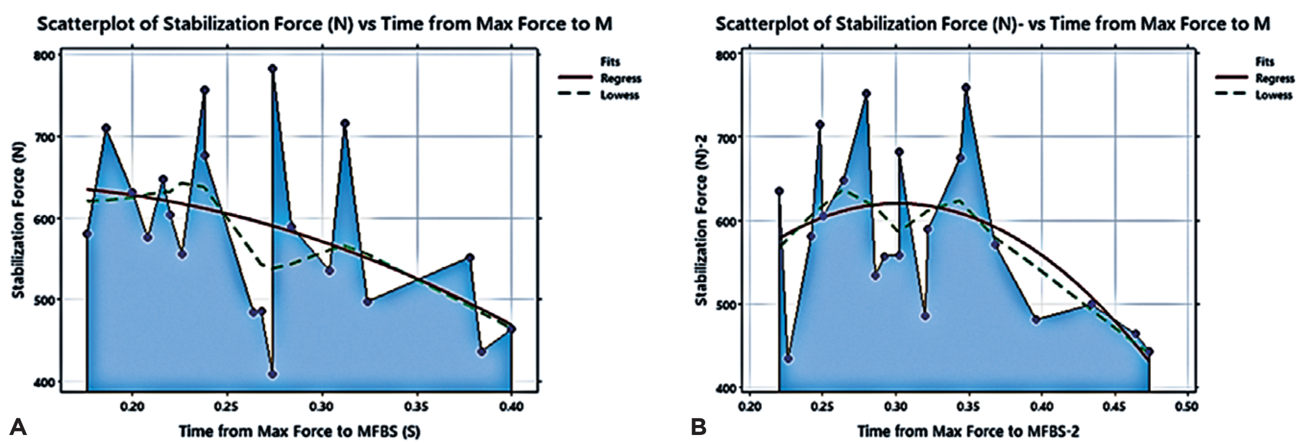

Figure 3. Scatterplot of stabilization force vs. time from max force to max force before stabilization (MFBS) with Regress and LOWESS fit models for a 33 cm jump height (A) and a 49 cm jump height (B).

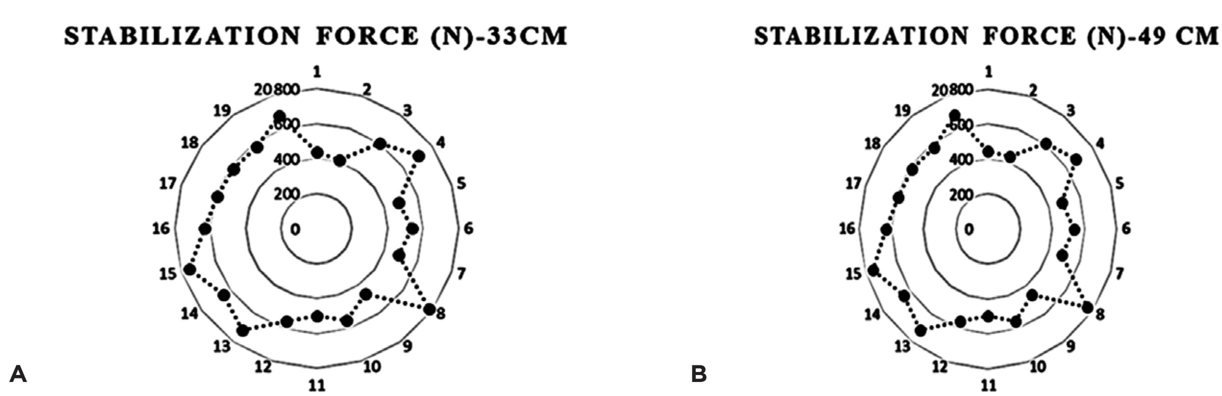

Figure 4. Radar chart of stabilization force in two jump heights, 33 cm (A) and 49 cm (B).

Discussion

Many human activities involve jumping and consequent landing, most commonly in dynamic activities like sports. These activities are usually associated with lower-limb musculoskeletal injuries, specifically in joints such as the hip, knee, and ankle. Toe fractures, ligament injuries, and ankle sprains are the most common injuries that happen without contact during the practice of dynamic activities. It is reported that

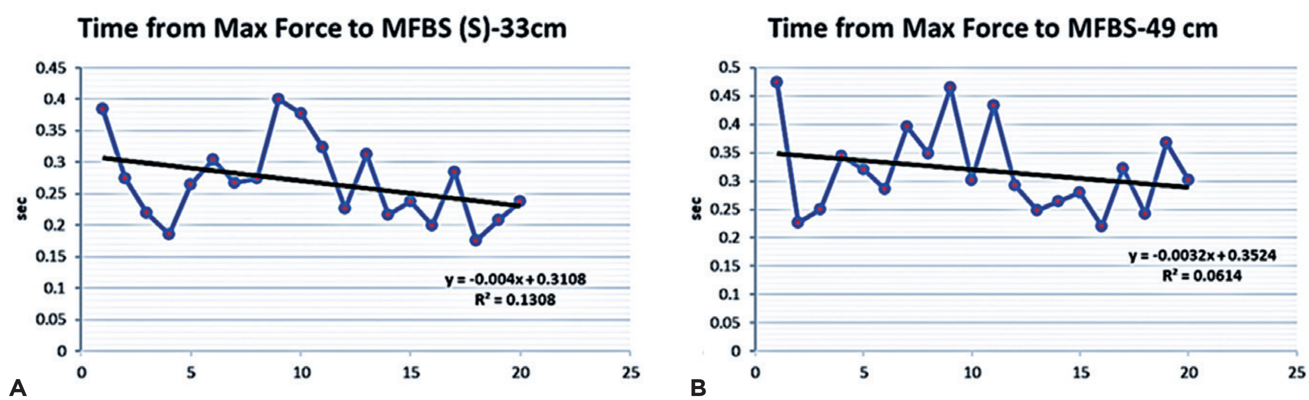

Figure 5. Line chart of time from max force to max force before stabilization (MFBS) in two jump heights, 33 cm (A) and 49 cm (B).

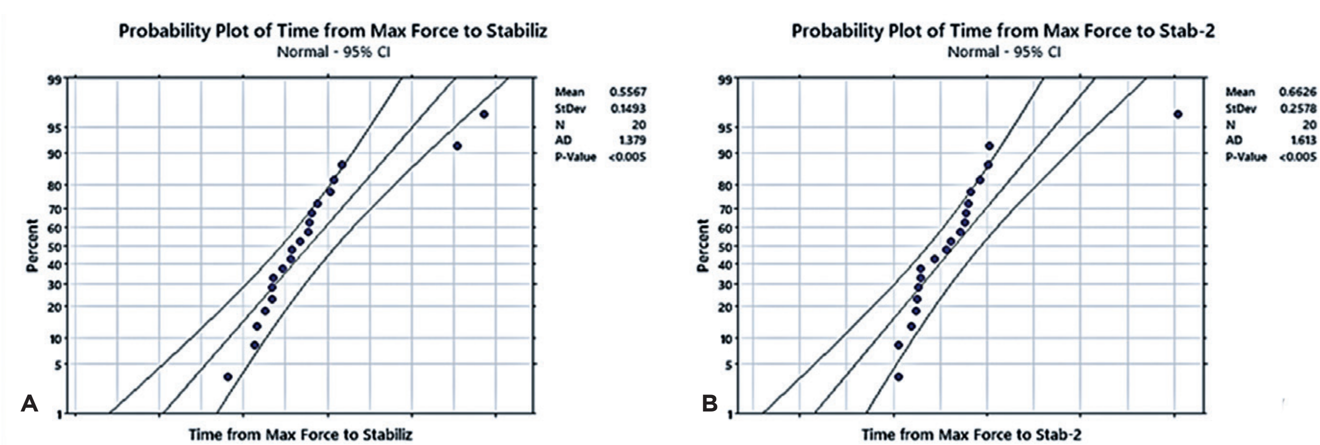

Figure 6. Probability plot of time from max force to stabilization in two jump heights, 33 cm (A) and 49 cm (B). Confidence interval: 95%.

Table 1. Barefoot kinetic dynamics

Parameters	Barefoot (N = 20)		Mann-Whitney U Test	Asymptotic Significance level
	Height: 33 cm (n = 20) Mean ±SD	Height: 49 cm (n = 20) Mean ±SD		
Initial contact force (N)	41.90 ± **21.618**	40.30 ± **19.480**	195	0.89 (p > 0.05)
Initial contact time (s)	2.12 ± **0.480**	2.22 ± **0.622**	208.5	0.81 (p > 0.05)
Max force (N)	3960.05 ± **2125.255**	4844.25 ± **2259.230**	268	0.06 (p > 0.05)
Max force time (s)	2.18 ± **0.477**	2.27 ± **0.622**	207	0.85 (p > 0.05)
Stabilization force (N)	584.40 ± **106.308**	583.35 ± **99.881**	201	0.97 (p > 0.05)
Time from max force to max force before stabilization (s)	0.27 ± **0.066**	0.32 ± **0.076**	279.5	**0.03 (p < 0.05)**
Time from max force to stabilization force (s)	0.56 ± **0.149**	0.66 ± **0.258**	264.5	0.08 (p > 0.05)

the jumping and landing biomechanics are closely related to the risk of acute injury due to prolonged exposure to high GRFs. Of course, landing biomechanics are related to muscle control, muscle fatigue, flexibility, and musculoskeletal stiffness, but these multiple factors collectively represent an individual's landing technique, which has been considered one of the most important factors related to injury potential. The technique employed directly affects the capacity of joints to absorb the energy associated with the large-magnitude GRFs experienced upon ground contact. Even though the joint kinematics is a significant factor in generally defining a good or poor landing technique, other variables affected by the overall technique and perhaps more directly associated with landing-related injuries are the moments occurring about the involved joints[7]**.** According to Roberts et al.[14], fractures sustained at forces ranging from 7854 N to 12206 N (mean: 9751 N) affected the calcaneus, tibia, and fibula bones[14]. Another study, by Begeman[15], reported intra-articular distal tibia fractures. In specimens with no injury, forces ranged from 3430 N to 7550 N (mean: 6157 N), and in specimens with fractures, forces ranged from 6110 N to 8690 N (mean: 7848 N)[15]. Yoganandan et al.[16] used data from these two abovementioned studies to derive a probability distribution based on Weibull analysis. According to the authors, a force of 6.8 kN represented a risk of injury of 50%[16]. One of the most common injuries experienced by individuals involved in physical activity is lateral ankle sprain and, after an acute ankle sprain, 32%–47% of patients report functional ankle instability[17].

This study aimed to investigate differences in toe kinetic variables at different drop heights to provide insights into balance and stability dynamics while barefoot forefoot jumping. This information is crucial for future design and development of footwear. Results revealed that barefoot balance dynamics provided a clear picture of balance and stability, which is important for making footwear that effectively absorbs forces during jumping activities before they reach the injury threshold.

During the initial contact phase, the subject's foot makes contact with the ground. The ground exerts a force on the subject (GRF) in response to this contact. The magnitude and direction of this force affects the subsequent phases of the jump. The initial force contributes to the subject's ability to overcome gravity and achieve vertical lift. A stronger initial force helps propel the body frontward, depending on the jump height. The force-time curve shows how the subject accelerates during this phase. The regression analysis of initial contact force vs. time indicated distinct patterns and curved fits, with R-squared values of 18.1% and 20.7% for drop heights of 33 cm and 49 cm, respectively. The study found that the initial contact force significantly affects the subject's stability during the take-off phase. Proper force distribution is essential for balanced movement and to prevent loss of control. Imbalances or asymmetries in force distribution and contact time may lead to suboptimal jumps or increased risk of injury. The illustrated image defines that the force vs. time distribution should ideally fall within the range of 35 N–40 N, reaching this level around 2.20 s into the activity. Understanding the initial contact force vs. time relationship helps individuals enhance their balance dynamics and maintain stability during any jumping activity. The significance of displayed data suggested a mirror idea of force absorption during jumping activities in general, including any sports and kids activities.

The scatterplot of max force vs. max force time also showed a dispersed pattern. Noticeable differences were observed between the regression fit model and the locally weighted scatterplot smoother (LOWESS) fit model. The regression analysis indicated R-squared values of 22.6% (33 cm) and 26.2% (49 cm) for the force vs. time fit model. This highlights the significant difference in force from the point of initial contact to reaching max force, with a large force difference occurring within 5 s–6 s. This could potentially lead to major foot injuries, especially in the metatarsal and phalanges. Excessive force during initial contact may also increase the risk of metatarsal stress fractures.

The muscle force component acting by the attached bone is called stabilization force. This force has a moment arm and is responsible for stabilizing the joint by producing the necessary amount of force. During a jump, the body goes through a sequence of movements known as triple extension, which includes ankle extension, knee extension, and hip extension[18]. Stabilization forces ensure efficient energy transfer from the ground to the body during this extension phase. Proper stabilization allows for maximal force generation, contributing to upward motion. During jumping activities, the stabilization force reduces the risk of injury during take-off and landing. It ensures proper alignment, balance, and control during the explosive phase of the jump. Without adequate stabilization, excessive forces or improper alignment can strain muscles, tendons, and ligaments[19]. This force minimizes energy loss due to unnecessary movement or misalignment. An efficient energy transfer ensures that the force generated during triple extension is effectively used for upward propulsion. Data analyzed in this study showed an 85% increase in force when reaching the maximum force achieved by the stabilization force within 0.56 s–0.66 s. Previous literature suggests that there should not be a significant difference in data between the contact force to max force and max force to stabilization. This difference could lead to acute ankle injuries and fractures. According to the radar chart analysis, the average stabilization force should be between 400 N and 500 N, and the time difference from when the maximum force is reached to when the stabilization force is achieved should be minimal.

Time from max force to stabilization is an important measure during jumping activities. It refers to the time it takes for an individual to regain stability after landing from a jump. It measures how quickly a person regains balance and control after the landing impact. When jumping from a height, the landing impact forces are significant, and a quick stabilization response reduces the risk of injury from excessive forces or misalignment[20]. Efficient stabilization ensures that the energy generated during the jump is effectively used for propulsion.

A faster time from max force to stabilization enables athletes to transition smoothly from landing to take-off, for example, in basketball, volleyball, or gymnastics. In non-athletic situations, rapid stabilization helps prevent falls and lowers the risk of injuries. An article by Kalra et al.[21] highlighted that metatarsal fractures are the most common traumatic foot injury, yet the thresholds for metatarsal fractures remain poorly characterized, affecting performance targets for protective footwear. In their experiment, these researchers studied impact energies, forces, and deformations to understand the risk of metatarsal fractures during workplace impact loading, finding that the most common fracture location was the second metatarsal. Average peak energy, force, and deformation during a fracture were 46.6 J, 4640 N, and 28.9 mm, respectively. By using survival analyses, they found that there was a 50% fracture probability associated with 35.8 J of impact energy and 3562 N of impact force[21].

The present study showed asymmetric lines regarding the time from maximum force to just before stabilization force for both jump heights analyzed. The regression analysis indicated R-squared values of 0.1308 and 0.0614, suggesting a risk of injury during landing. The probability plot indicated that the study results were within the 95% confidence interval, but not between mean values. Furthermore, rapid stabilization is crucial after the initial contact within a minimum time[22]. However, the study did not find significant correlations between static/dynamic core stability and jumping height. As a result, individuals with higher core stability should have improved dynamic performance, better balance, and firmer stability.

Limitation

The current study had limitations such as a small sample size and the inclusion of only barefoot forefoot jumping from two different heights in laboratory conditions. In the future, for a better understanding of kinetic responses, a similar study with a larger sample size and with and without different types of footwear should be carried out to help translate the findings hereof to real field conditions.

Conclusion

The present study revealed that barefoot jump from a height of 49 cm exerts more impact on the forefoot, except for the initial contact and stabilization force, as compared to a 33 cm jump regarding the studied parameters. The only factor found to significantly affect the subject's stability during take-off is the time from max force to max force before stabilization (s), which represents the time between reaching maximum force and achieving stable balance after landing. It reflects how quickly subjects transition from generating force during take-off to controlling that force during landing. This efficient energy transfer ensures that the force generated during the jump contributes optimally to upward motion and minimizes energy loss. A rapid transition from max force to stabilization reduces the risk of injury. If an athlete remains in a high-force state for too long (e.g., due to delayed stabilization), they can strain muscles, tendons, and ligaments upon landing. A shorter time to stabilization allows athletes to smoothly transition from the eccentric (braking) phase to the concentric (propulsion) phase, having a lower risk of injury. Quicker stabilization also enables faster recovery for subsequent movements, such as another jump or a change of direction.

The force vs. time plot for initial contact exhibited scattered patterns and poor fit, with low R-squared values of 18.1% and 20.7% for drop heights of 33 cm and 49 cm, respectively. The maximum force recorded at 33 cm was 3960.05 N, and at 49 cm, it was 4844.25 N, which is 68% closer to the values associated with metatarsal fractures (as 3562 N of force has a 50% probability of causing a fracture). Stabilization force during barefoot forefoot jumping was 584.40 N at 33 cm and 583.35 N at 49 cm. The difference between the minimum force and the stabilization force was 71.37% at 33 cm and 82.11% at 49 cm. It was revealed that an efficient and rapid stabilization is necessary to achieve a better balance and firmer stability after jumps from heights. This kinetic data will be beneficial and set standard values for the optimization of material properties in sports and children's footwear to reduce the risk of foot injuries.

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Original Article

Return to work in patients with an ankle fracture and the influence of physiotherapy

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Abstract

Objective: The aim of this study is to assess the influence of physiotherapy on return to work (RTW) in patients with an ankle fracture.

Methods: A retrospective cohort study was conducted on patients 18 years and older with an ankle fracture submitted to conservative treatment or surgery in one of four regional hospitals in the Netherlands between 2017 and 2019. Patient and treatment characteristics were extracted from medical records. Questionnaires were sent to patients regarding information about RTW.

Results: One thousand eight hundred and four patients met the inclusion criteria, and 1163 patients replied to the questionnaire (64.5%). The patients were divided into two groups: those who received physiotherapy (n = 573) and those who did not (n = 582). Patients who had physiotherapy were more often older, female, had more inherently unstable and open fracture types, were submitted to surgery, treated using cast immobilization, experienced complications, and needed revision surgery more often. Physiotherapy was seen to be a significant negative associative factor for RTW (HR = 0.768).

Conclusion: Overall, 5% of all patients sustaining an ankle fracture did not RTW. Although partly explained by fracture characteristics, treatment type, and patient factors, physiotherapy appears to negatively affect time to RTW in patients with an ankle fracture.

Level of Evidence II; Prognostic study; Retrospective study.

Keywords: Ankle fractures; Physiotherapy; Return to work.

Introduction

After sustaining an ankle fracture, adults often experience a rapid initial recovery, but functional improvement declines over time. On average, it is suggested that no further improvement can be expected after 24 months[1]. Early rehabilitation is highly preferable when treating ankle fractures to improve functional outcomes[2].

Rehabilitation is often directed by a physiotherapist and is suggested to be beneficial in restoring mobility to impaired extremities. For instance, when patients with distal radius fractures are treated with physiotherapy, pain perception is decreased[3-6]. However, in terms of function, no clear benefit is seen[4,5]. Moreover, no clear benefit of physiotherapy is seen in patients with ankle distortion regarding functional recovery[7]. In line with these results, the effect of physiotherapy on functional outcomes after sustaining an ankle fracture is questioned[8].

Nevertheless, it is important to acknowledge that functionality is affected not only after sustaining an ankle fracture. Trauma patients face psychological but also social consequences, such as delayed return to work (RTW)[9,10]. It is well-established that several factors affect the ability to

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RTW following an ankle fracture, including the ability to bear weight[11-13]. To date, the exact influence of physiotherapy on RTW in patients with an ankle fracture remains unknown[14,15].

The primary aim of this study is to assess the influence of physiotherapy on RTW in patients with an ankle fracture.

Methods

Study design and eligibility criteria

A retrospective cohort study was conducted to assess the effect of physiotherapy on time to RTW. It was conducted in four regional teaching hospitals in the eastern Netherlands. Two hospitals are Level I trauma centres, and the others are Level II trauma. Ethical approval was obtained from local medical ethics committees. The study population was patients with an ankle fracture treated at one of the four participating hospitals between 1st August 2016 and 31st April 2020. Patients in this study had to be at least 18 years and older and master the Dutch language to answer the questionnaire. Patients submitted to conservative treatment and surgery were included. Patients who met the inclusion criteria and completed the questionnaire were included for analysis in this study. Patients with pilon fractures were excluded.

Study variables

Data was extracted from medical records of patients treated in one of the participating hospitals. Patient details, fracture characteristics, and treatment specifics were extracted from the records. All data was managed using the online Castor Electronic Data Capture software[16].

Patient data extracted from medical records were age, sex, date of the accident, American Society of Anaesthesiologists (ASA) classification as described by the anaesthesiologist in the pre-operative screening, and smoking as reported by the treating surgeon or anaesthesiologist[17].

The obtained fracture characteristics were the type of fractures classified by Danis-Weber and Lauge Hansen and whether or not it was a compound fracture (using Gustilo-Anderson classification)[18,19]. Fractures were analysed and classified by medical researchers. In case of uncertainties, three trauma surgeons were consulted.

The following treatment characteristics were extracted: conservative treatment or surgery, cast immobilization or functional treatment, and whether or not rehabilitation was directed by a physiotherapist. Complications such as superficial and deep infections, peripheral nerve damage, bleeding, malunion, nonunion, failure of osteosynthesis material, and if revision surgery was deemed necessary by the treating physician were assessed. Superficial wound infections were defined as treated with oral antibiotics only. Wound infections treated with intravenous antibiotics and/or surgical debridement were defined as deep infections. Peripheral nerve damage was defined as the loss of sensibility in the ankle or foot three months after surgery. If a blood transfusion was given or surgery was needed due to bleeding, it was considered post-operative bleeding. Malunion, nonunion, and failure of the osteosynthesis material were diagnosed by the treating physician.

Outcome measures

The primary outcome of this study was time to RTW in days. For conservative treatment, time to RTW was measured from the accident date. For surgery, it was measured from the date of surgery.

Return to work

Questionnaires were sent after record extraction to measure the time to RTW. They were emailed if an email address was available from the patients' records; otherwise, the questionnaire was sent by mail. A reminder was sent after two weeks if a patient did not respond to the email. Patients who did not respond to this reminder or the questionnaire sent by mail were called by phone. In total, patients were called no more than three times.

Questions about whether and when patients did RTW were asked. Patients could choose from three options: yes, no, and not applicable. For various reasons, patients who filled in 'no' could not RTW after injury. For RTW, not applicable was chosen when patients did not have a job before the injury and had already stopped working before the injury because of retirement or other illnesses. Smoking was also questioned in the questionnaire. The total years of smoking and number of cigarettes per day were asked to calculate the amount of packyears.

Statistical analysis

Descriptive statistics were used to describe the study population. Bivariable analysis was executed for main characteristics, including the Chi-square and Mann-Whitney U test. Number of patients who did not RTW was calculated among subgroups based on known factors that influence either returning to work or the need for physiotherapy. For further analysis regarding RTW, only patients who returned to work were considered. A univariable and multivariable Cox regression analysis was performed to evaluate the association of different variables on the time to RTW. In case of low numbers, subgroups were combined. Statistical analysis was performed using SPSS software version 29.0.0.0.

Results

Patients' characteristics

From 1st January 2017 to 31st December 2019, 1804 patients met the inclusion criteria, and 1163 patients completed the questionnaire (64.5%). The median follow-up time was 889 days (2.4 years) from the date of injury (for conservative treatment) or the date of surgery (for surgery).

Patients who completed the questionnaire were more often female (55.9% vs 62.9%), non-smoking (64.5% vs 73.3%), had fewer comorbid diseases (ASA 1 and 2: 78.5% vs 86.9%), had more severe fractures types (Lauge Hansen pronation external rotation 4 (PE4) 7.0% vs 8.8%, supination external rotation 4 (SE4) 24.4% vs 29.0%), attended physiotherapy more often (42.9% vs 49.6%) and received more operative treatment (37.7% to 51.7%) (Table 1).

Table 1. Patients who completed the questionnaire vs patients who did not complete the questionnaire

			Questionnaire completed		Significance
			No (n = 640)	Yes (n = 1163)	
Age in years (median)			52.0 (32.0 to 71.0)	54.0 (40.0 to 65.0)	*p* = 0.950*
Sex	Male		282 (44.1%)	432 (37.1%)	
	Female		358 (55.9%)	731 (62.9%)	***p* = 0.004****
Smoking	No		231 (64.5%)	550 (73.3%)	
	Yes		127 (35.5%)	200 (26.7%)	***p* = 0.003****
ASA-classification	1		93 (33.3%)	228 (34.8%)	
	2		126 (45.2%)	341 (52.1%)	
	3		50 (17.9%)	78 (11.9%)	
	4		10 (3.6%)	8 (1.2%)	***p* = 0.005****
Weber- classification	Weber A		160 (25.7%)	314 (27.5%)	
	Weber B		384 (61.6%)	665 (58.3%)	
	Weber C		79 (12.7%)	162 (14.2%)	*p* = 0.378**
Lauge Hansen classification	SE	1	1 (0.2%)	0 (0.0%)	
		2	175 (27.5%)	273 (23.6%)	
		3	23 (3.6%)	22 (1.9%)	
		4	155 (24.4%)	335 (29.0%)	
	SA	1	111 (17.5%)	227 (19.6%)	
		2	40 (6.3%)	46 (4.0%)	
	PE	1	18 (2.8%)	30 (2.6%)	
		2	1 (0.2%)	5 (0.4%)	
		3	29 (4.6%)	51 (4.4%)	
		4	46 (7.0%)	102 (8.8%)	
	PA	1	9 (1.4%)	20 (2.5%)	
		2	0 (0.0%)	2 (0.2%)	
		3	7 (1.1%)	17 (1.5%)	
	Not classifiable		21 (3.3%)	21 (1.8%)	***p* < 0.013****
Gustilo-Anderson classification	Closed		621 (97.9%)	1135 (97.9%)	
	I		3 (0.5%)	9 (0.8%)	
	II		5 (0.8%)	7 (0.6%)	
	III		5 (0.8%)	8 (0.7%)	*p* = 0.235**
Surgery	No		397 (62.3%)	561 (48.3%)	
	Yes		240 (37.7%)	600 (51.7%)	***p* < 0.001****
Physiotherapy	No		360 (57.1%)	582 (50.4%)	
	Yes		271 (42.9%)	573 (49.6%)	***p* = 0.007****
Cast immobilization	No		89 (14.0%)	186 (16.0%)	
	Yes		547 (86.0%)	975 (84.0%)	*p* = 0.254**
Complication after surgery	No		598 (93.4%%)	1048 (90.1%)	
	Yes		42 (6.6%)	115 (9.9%)	***p* = 0.017****
Revision surgery	No		616 (98.2%)	1124 (97.3%)	
	Yes		11 (1.8%)	31 (2.7%)	*p* = 0.217**

* Mann-Whitney U test; ** Chi-squared test
ASA: American Society of Anaesthesiologists; SE: Supination external; SA: Lauge Hansen; PE: Pronation external.

The main reasons for not responding to the questionnaire were no interest in participating, an invalid phone number or (email-) address, and not answering the phone and/or email. Among the included patients, 1163 answered the questionnaire, and the patients were divided into two groups: patients treated with physiotherapy (n = 582) and patients not treated with physiotherapy (n = 573). There were eight missing values for the variable physiotherapy. For further analysis, only patients who completed the questionnaires were considered.

Baseline characteristics

Overall, patients were middle-aged (median 52.0 (IQR 35.0 to 64.0) vs 54.0 years (IQR 39.0 – 68.0)), and in both groups were more female patients (58.8% and 67.0%). In the physiotherapy group, more Weber B (48.2% vs 68.6%) and C (9.6% vs 19.2%) fracture types were seen, and fewer Weber A fracture types (42.4% vs 12.2%). Thereby, more inherently unstable fractures were noticed, such as SE4 (n = 248 vs n = 85) and PE4 (n = 73 vs n = 29). Lauge Hansen (SA1) was less frequently treated with physiotherapy (n = 188 vs n = 37) (Table 2). Consequently,

Table 2. Baseline characteristics between physiotherapy and no physiotherapy groups

			Rehabilitation		Significance
			No physiotherapy (n = 582)	Physiotherapy (n = 573)	
Age in years (median)			52.0 (35.0 to 64.0)	54.0 (39.0 to 68.0)	
					p* = 0.001
Sex	Male		240 (41.2%)	189 (33.0%)	
	Female		342 (58.8%)	384 (67.0%)	
					p* = 0.004*
ASA-classification	1		81 (38.6%)	145 (32.7%)	
	2		101(48.1%)	240 (54.2%)	
	3		25 (11.9%)	53 (12.0%)	
	4		3 (1.4%)	5 (1.1%)	
					p = 0.472**
Weber-classification	Weber A		243 (42.2%)	68 (12.2%)	
	Weber B		277 (48.2%)	383 (68.6%)	
	Weber C		55 (9.6%)	107 (19.2%)	
					p* < 0.001*
Lauge Hansen classification	SE	1	0 (0.0%)	0 (0.0%)	
		2	168 (29.1%)	103 (18.1%)	
		3	11 (1.9%)	11 (1.9%)	
		4	85 (14.7%)	248 (43.5%)	
	SA	1	188 (32.5%)	37 (6.5%)	
		2	26 (4.5%)	18 (3.2%)	
	PE	1	17 (2.9%)	13 (2.3%)	
		2	3 (0.5%)	2 (0.3%)	
		3	18 (3.1%)	33 (5.8%)	
		4	29 (5.0%)	73 (12.8%)	
	PA	1	14 (2.4%)	11 (1.9%)	
		2	1 (0.2%)	1 (0.2%)	
		3	5 (0.9%)	12 (2.1%)	
	Not classifiable		13 (2.3%)	8 (1.4%)	
					p* < 0.001*
Gustilo-Anderson classification	Closed		578 (99.3%)	549 (95.8%)	
	I		3 (0.5%)	6 (1.1%)	
	II		0 (0.0%)	7 (1.2%)	
	III		1 (0.2%)	11 (1.9%)	
					p* = 0.011*
Surgery	No		415 (71.4%)	143 (25.0%)	
	Yes		166 (28.6%)	430 (75.0%)	
					p* < 0.001*
Cast immobilization	No		109 (18.7%)	77 (13.5%)	
	Yes		473 (81.3%)	495 (86.5%)	
					p* = 0.015*
Complication	No		557 (95.7%)	483 (84.3%)	
	Yes		25 (4.3%)	90 (15.7%)	
					p* < 0.001*
Revision surgery	No		574 (99.1%)	545 (95.4%)	
	Yes		5 (0.9%)	26 (4.6%)	
					p* < 0.001*

* Mann-Whitney U test; ** Chi-squared test.
ASA: American Society of Anaesthesiologists; SE: Supination external; PE: Pronation external.

significant differences were seen in the number of operated patients ($p < 0.001$), the number of complications ($p = 0.015$) as well as patients who needed revision surgery ($p < 0.001$) in the physiotherapy group (Table 2). ASA- classification stages 3 and 4 were combined in the analysis due to the low number of patients. Concerning the Gustilo-Anderson classification, further analysis combined 3 A, B, and C as stage 3 or noted as open vs closed.

The median days between injury and completing the questionnaire (follow-up time) was 931 days (2.5 years) (IQR of 600 – 1210 days) for the no physiotherapy group compared to 847 days (2.3 years) (IQR of 551 – 1133.5 days) for the physiotherapy group, which was a significant difference between groups ($p = 0.024$).

Table 3. Comparison of patients who did not return to work between physiotherapy and no physiotherapy groups

		Rehabilitation		
		No physiotherapy	Physiotherapy	All patients
Age (years)	< 40	3 (2.0%)	13 (9.1%)	16 (5.4%)
	> 40	10 (2.3%)	32 (7.5%)	42 (4.9%)
Weber-classification	Weber A	4 (1.7%)	5 (7.5%)	9 (2.9%)
	Weber B	7 (2.6%)	29 (7.7%)	36 (5.5%)
	Weber C	2 (3.6%)	8 (7.7%)	10 (6.3%)
Surgery	Yes	8 (4.8%)	39 (9.1%)	47 (7.9%)
	No	5 (1.2%)	6 (4.3%)	11 (2.0%)

Primary outcome

Almost two-thirds (63.3%) of patients returned to work after sustaining an ankle fracture within the follow-up time. Others did not RTW after injury (5.0%), had already stopped working before the date of injury (31.0%), or did not answer the question (0.7%). When comparing patients who attended physiotherapy and patients who did not, it showed that patients who attended physiotherapy did more often not RTW after sustaining an ankle fracture in all subgroups (age, Weber classification, and operation) (Table 3). The highest percentages of patients who did not RTW were seen among those younger than 40 (9.1%) and those submitted to surgical treatment (9.1%).

Cox regression analysis

A Cox regression analysis was performed to demonstrate which factors are associated with time to RTW. In the univariable analysis, many variables were found to be significant. In the multivariable analysis, a significant association with time to RTW was seen within the variables operated (HR 0.612, 0.394 to 0.950), physiotherapy (HR 0.768, 0.607 to 0.972), cast immobilization (HR 0.660, 0.501 to 0.870) and complications (HR 0.694, 0.519 to 0.930) (Table 4).

Discussion

In our study, a total of 5% of all patients sustaining an ankle fracture were not able to RTW. In addition, several factors contribute to a prolonged time for RTW, such as cast

Table 4. Univariable and multivariable cox-regression analysis

		Univariable			Multivariable		
		HR (Exp B)	p-value	95% confidence interval for Exp B	HR (Exp B)	p-value	95% confidence interval for Exp B
Sex	Male	RC			RC		
	Female	0.929	0.339	0.798 to 1.081	0.898	0.341	0.720 to 1.121
Age	< 40 years	RC			RC		
	> 40 years	0.976	0.766	0.833 to 1.144	0.842	0.158	0.663 to 1.069
ASA-classification	1	RC			RC		
	2	1.054	0.617	0.859 to 1.292	1.087	0.461	0.871 to 1.356
	3 and 4	0.805	0.361	0.507 to 1.281	0.816	0.414	0.502 to 1.328
Gustilo-Anderson classification	Closed	RC			RC		
	Open	0.541	***0.030***	0.311 to 0.942	0.790	0.427	0.443 to 1.411
Weber classification	A	RC			RC		
	B	0.648	***<0.001***	0.543 to 0.773	1.309	0.175	0.887 to 1.933
	C	0.484	***<0.001***	0.378 to 0.620	1.043	0.844	0.685 to 1.588
Surgery		0.467	***< 0.001***	0.401 to 0.545	0.612	***0.029***	0.394 to 0.950
Physiotherapy		0.541	***< 0.001***	0.464 to 0.630	0.768	***0.028***	0.607 to 0.972
Cast immobilization		0.690	***< 0.001***	0.564 to 0.846	0.660	***0.003***	0.501 to 0.870
Complications		0.567	***< 0.001***	0.435 to 0.740	0.694	***0.014***	0.519 to 0.930

HR: Hazard ratio; RC: Reference category; ASA: American Society of Anaesthesiologists.

immobilization, surgery, or post-operative complications. Lastly, physiotherapy appears to have a negative impact on the time to RTW.

The finding of our study is in line with the study by Moseley et al.[15], in which physiotherapy was compared to advice only on functional outcome and RTW. This study showed no benefit of physiotherapy over advice only. Additionally, no significant difference was seen in time to RTW. However, a small difference was seen in time to RTW, whereas attending physiotherapy seems to have a longer time to RTW (median time: 23 days vs 32 days) compared to patients who only had advice[15]. So far, it is unclear what caused this prolonged time for RTW. It might be caused by the fact that more complex fractures more often attend physiotherapy, although multivariable regression analysis corrected Weber and Gustilo-Anderson's classification. Another interpretation might be that physiotherapists are intrinsically more cautious with active aftercare than medical specialists.

Apart from physiotherapy several other factors significantly influenced the time to RTW.

Firstly, patients submitted to surgery appear to be associated with a delay in returning to work. This aligns with a study on patients with distal radius fractures, where surgery led to a longer time from work than conservative treatment[20]. Surgical treatment might be considered a proxy for more complex fractures, whereas more complex fractures could lead to worse outcomes[21]. These worse functional outcomes could explain a delay in returning to work[22]. Second, cast immobilization appeared to be a significant factor. Studies show that active exercise accelerates daily activities, functional outcomes, and RTW compared to immobilization[12]. Therefore, cast immobilization can lead to a delay in RTW. Thereby, cast immobilization could lead to ankle stiffness and affect functional outcomes[6,23].

Lastly, complications following surgical treatment also cause a prolonged time to RTW. Complications lead to impaired functional scores[24]. Consequently, this could explain why lower functional outcomes are associated with a decreased RTW[22].

In our study, 5% could not RTW after sustaining an ankle fracture. Other studies in the Netherlands, the USA, and Australia showed higher unemployment rates of 8% to 15.7% in patients after sustaining an ankle fracture[9,25]. An explanation for the higher unemployment rate of these studies could be due to differences in sample sizes and differences in social support and health care systems among these countries.

Our study has several limitations. First, the questionnaire response rate was 64.5%, and some significant differences were seen in patients who completed the questionnaire and patients who did not, which could potentially lead to selection bias. Another limitation is that the exact content and frequencies of physiotherapy treatment were unknown. It is reasonable to think that both aspects influence functional outcomes. Thereby, it is known that many factors influence functional outcomes and RTW. It is possible that some of these influencing factors were not accounted for in our analysis. For example, the kind of work performed, the content of the physiotherapy, or psychological aspects of rehabilitation (i.e. kinesiophobia) since there is a growing amount of evidence suggesting a relation between psychological factors and clinical outcome after trauma[13,26-28].

The strengths of this study include that this study is a multicentred study; therefore, the study population size is large enough to show a significant difference and have a good representation. Lastly, the median follow-up time was 2.4 years, which allowed patients to recover from an ankle fracture and a high possibility of RTW.

Conclusion

Our study showed that 5.0% of all patients sustaining an ankle fracture did not RTW. Although partly explained by fracture characteristics, treatment type, and patient factors, physiotherapy appears to negatively affect time to RTW in patients with an ankle fracture. Further research should be performed to assess the impact of the type of labour (i.e. manual and/or heavy labour) on RTW, the exact content of physiotherapy, and the role of a physiotherapist in the context of kinesiophobia.

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Original Article

Comparative study of arthroscopic treatment of osteochondral lesions of the talus

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Abstract

Objectives: Evaluate and compare, through the American Orthopedic Foot and Ankle Society (AOFAS) score, the clinical and functional results of arthroscopy treatment of osteochondral lesions of the talus with bone marrow stimulation with or without association with the autologous matrix-induced chondrogenesis.

Methods: A retrospective comparative clinical study with 56 patients diagnosed with osteochondral lesions of the talus, eight of whom did not agree to participate in the study, 35 were submitted to surgical treatment with subchondral bone microperforation, and 13 to microperforation associated with collagen matrix membrane. The Mann-Whitney test was applied to compare continuous measurements between the two groups. The significance level adopted for the statistical tests was 5%.

Results: After intragroup analysis, the microperforation treatment group associated with collagen matrix membrane, all patients improved the AOFAS score (55.0 to 90.0). In the treatment with bone marrow stimulation, patients increased the AOFAS from 57.0 to 90.0. In the treatment with collagen matrix membrane, patients increased the AOFAS score from 51.0 to 90.0. There was no significant difference between the groups studied.

Conclusion: Both treatments, through ankle arthroscopy, can be great treatment options for osteochondral lesions of the talus, according to their specific indications, with significant functional and clinical improvement, identified by the increase in the AOFAS score.

Level of Evidence III; Retrospectivef comparative study; Therapeutic studies - investigating the results of treatment.

Keywords: Arthroscopy; Talus; lesion; Injuries.

Introduction

Osteochondral lesions of the talus (OLT) are defined as erosions of the chondral layer and subchondral bone of the talus. They become important due to the cause of residual pain and functional deterioration after ankle sprains or other traumatic injuries, with an increased need for arthrodesis and arthroplasty of this joint. Hyaline cartilage has low metabolic activity, being avascular and hypocellular, which hinders the remodeling process and maintains residual defects after an injury[1]. The etiology of the injuries may be of traumatic or non-traumatic origin. Compared to cartilage injuries, OTL is more often caused by trauma, and the longer the time elapses between trauma and injury, the more severe the associated chondral injury becomes[2]. Among non-traumatic causes, vascular etiology is one of the most common causes[3]. In the study by DiGiovanni et al.[4], OLT was identified in 23.0% of patients diagnosed with chronic ankle instability. In general, medial lesions are shown in 62.9% of cases, lateral lesions appear in 33.4% of cases, and those of the central third are shown in 3.7%[5].

Study performed at the Department of Orthopedics and Traumatology, Pontificia Universidade Catolica de Campinas (PUC-CAMPINAS), Campinas, SP, Brazil.

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Magnetic resonance imaging (MRI) is the best imaging method for diagnosing and postoperative evaluation of OTL[6]. It was used in this study to assist in evaluating the lesion size. Computed tomography can also identify the lesion's depth, which can modify the proposed treatment.

Among the treatment options described, we can mention bone marrow stimulation[7,8], autologous grafts[8,9], heterologous grafts[10,11], and chondrocyte-inducing matrices[12-14]. The latter, also called autologous matrix-induced chondrogenesis (AMIC), is a very viable option to treat OTL involving stimulation of the bone marrow of the subchondral bone and application of a type I and III collagen bilaminal membrane, which works by protecting and stabilizing the chondrogenic cells that are stimulated after bone marrow perforation. When the subchondral bone defect is too large, a bone graft can fill the gap before the installation of the inducing matrix[14].

Regarding bone marrow stimulation, they can be used as a technique aimed at inducing healing by removing unstable cartilage segments and perforating the subchondral bone, producing bleeding, clot formation, and fibrocartilage; thus, trying to avoid early arthrosis[15].

With the data in the literature and previous studies, there is no consensus on a more advantageous treatment[16,17].

The objective of this study is to evaluate and compare, through the American Orthopedic Foot and Ankle Society (AOFAS) score[18], the clinical and functional results of arthroscopy treatment of OTL with bone marrow stimulation with or without association with the autologous matrix-induced chondrogenesis.

Methods

The study was approved by the Institutional Review Board. A retrospective comparative clinical study with 56 patients diagnosed with OTL, eight of whom were excluded from the study due to not agreeing with the terms described in the Informed Consent Form. The patients were submitted to surgical treatment by four experienced surgeons with bone marrow stimulation through subchondral bone microfractures (35 patients) and bone marrow stimulation associated with AMIC – collagen membrane I and III (13 patients). The surgical treatment indicated was based on the symptomatology of the patient with ankle pain, such as signs of joint instability and sprains, in addition to examination of radiographic images based on Berndt and Harty's classification[19] and MRI demonstrating OTL. The classification was performed on radiographic images due to the low quality of MRI in some patients and the absence of concise intraoperative reports describing the lesions. The follow-up period within the study was approximately 36 months after the arthroscopic intervention when the AOFAS questionnaire was applied. All patients were submitted to anterior ankle arthroscopy, and interventions were performed simultaneously with bone marrow stimulation and membrane placement. The postoperative period was performed with restrained weight-bearing in the first 6-8 weeks, and then weight-bearing was released gradually according to pain. All patients underwent physiotherapy starting in the second week after surgery.

Two groups submitted to arthroscopic treatment of OTL were analyzed: the group in which bone marrow stimulation was performed and the group in which collagen membrane was performed. The size measurement used to compare the lesions was centimeters (cm), with the identified sizes ranging from 0.5 x 0.5 cm to 1.5 x 1.5 cm. It was impossible to identify the lesions' depth and the subchondral bone's viability due to missing data in the intraoperative records. The first group (Membrane group) was submitted to spinal cord stimulation combined with AMIC, and the second (Microperforation group) was submitted to exclusive spinal cord stimulation with microperforation of the chondral lesion. They were evaluated in the pre-and postoperative using the AOFAS questionnaire to evaluate the pain, functional limitation due to lesion, and the patient's quality of life.

Inclusion criteria

Patients over 18 years of age, of both sexes, with ankle pain caused by sprain, ankle fracture, and unspecified chronic pain associated with osteochondral injury were included in the study. All selected lesions can be classified according to Berndt and Harty's classification—all patients who followed the protocol and maintained postoperative follow-up.

Exclusion criteria

Patients who did not agree to participate in the study and did not sign the Informed Consent Form, patients in whom lesion causes or sizes could not be identified, patients with a history of surgery for previous osteochondral lesion, and patients who lost follow-up postoperatively were excluded from the study.

Statistical analysis

The patients included in the study were submitted for anamnesis, physical examination, and AOFAS questionnaire. After surgical treatment, between six months and two years, the AOFAS questionnaire was reapplied.

To describe the characteristics of the sample, frequency tables of categorical variables were performed with values of absolute frequency (n) and percentage (%), and, for quantitative variables, descriptive measures (mean, standard deviation, minimum, median, and maximum) were obtained. When necessary, the Chi-square test or Fisher's exact test was used to compare proportions. The Mann-Whitney test was applied to compare continuous measurements between the groups[20].

The ANOVA for repeated measures with transformation by rank was applied to evaluate the AOFAS score related to the groups, times, and other variables. The significance level adopted for the statistical tests was 5%[20,21].

Results

Overall analysis

Forty-eight patients submitted to ankle arthroscopy were included in the study, the mean age was 55.5 years, with a prevalence of males (56.3%) compared to females (43.8%). The main cause was chronic pain (50%), followed by sprain (45.8%), and only two cases were post-ankle fracture (4.2%). The lesion sizes visualized in the imaging exams had a median of 1.0 cm. The questionnaire applied before each surgery had a median score of 55.0 and the postoperative questionnaire of 90.0, as shown in Table 1.

Intragroup analysis

In this analysis, as shown in Table 2, no statistical difference was detected between the pre-and post-moments for all comparisons of age (p = 0.2961), size (p = 0.6163), sex (p = 0.3902) and cause (p = 0.5427) in both groups.

Intergroup analysis

As can be seen in Table 3, a descriptive analysis and AOFAS comparison between the groups was performed, and no significant differences (p = 0.2990) were found in the pre- and post-arthroscopy measurements. In both groups, there was an increase in the independent score of the variables, as identified in Figure 1, with an increase from 51.0 to 90.0 in the membrane group and 57.0 to 90.0 in the microperforation group.

Results of interest

An evaluation of the effect of age and lesion size identified on MRI compared with pre-and post-arthroscopy scores in both groups was performed. The size measurement used to compare the analyzed lesions was centimeters. Table 4 shows a significant increase in the score after surgery, regardless of lesion size (p = 0.7218) or age (p = 0.2715).

Descriptive analyses were performed comparing the AOFAS score when related to sex (Table 5), where the mean score in females before arthroscopy was 56.0 and post 90.0, and in males, it was 55.0 to 90.0.

The causes were analyzed individually according to the complaints reported in the medical record for seeking care, indication and performance of ankle arthroscopy. Due to the traumatic origin in both cases, the sprains and fractures were grouped in the same subgroup to facilitate statistical comparisons. All patients underwent the same treatment protocol, being released for physiotherapy two weeks after surgery, with suspension of the weight-bearing until about 6-8 weeks, being released gradually according to the patient's pain tolerance. Table 6 shows that in all groups, there was an increase in the score after surgery, regardless of the cause, with chronic pain progressing from 56.0 to 88.5 and in the traumatic order from 54.5 to 90.0.

Discussion

Based on the analyses performed in the study, an improvement in the AOFAS score in all groups after arthroscopy could be

Table 1. Descriptive overall analysis

Variables	(n = 48)
Age (Mean ± SD)	52.44 ± 10.74 (n = 48)
Age (Median (min-max)	55.50 (29.00-70.00)
AOFAS Pre (Mean ± SD)	54.13 ± 21.70 (n = 48)
AOFAS Pre (Median (min-max)	55.00 (6.00-92.00)
AOFAS Post (Mean ± SD)	85.33 ± 15.70 (n = 48)
AOFAS Post (Median (min-max)	90.00 (45.00-100.00)
Bigger size (Mean ± SD)	1.04 ± 0.34 (n = 48)
Bigger size (Median (min-max)	1.00 (0.50-1.50)
Variables	**n (%)**
Group	
Membrane	13 (27.1)
Microperfuration	35 (72.9)
Sex	
Female	21 (43.8)
Male	27 (56.3)
Cause	
Chronic pain	24 (50.0)
Sprain	22 (45.8)
After medial malleolus fracture	2 (4.2)

AOFAS: American Orthopedic Foot and Ankle Society; SD: Standard deviation; Min-Max: Minimum-Maximum.

Table 2. Descriptive analysis and comparison between groups

Variables	Membrane group (n = 13)	Microperfuration group (n = 35)	Total (n = 48)	p-value
Age (Mean ± SD)	50.31 ± 8.89	53.23 ± 11.37	52.44 ± 10.74	0.2961[1]
Age (Median, min-max)	50.00 (35.00-62.00)	56.00 (29.00-70.00)	55.50 (29.00-70.00)	
Bigger size (Mean ± SD)	10 ± 0.35	1.06 ± 0.34	1.04 ± 0.34	0.6163[1]
Bigger size (Median, min-max)	1.00 (0.50-1.50)	1.00 (0.50-1.50)	1.00 (0.50-1.50)	
Sex				
Female	7 (53.8%)	14 (40.0%)	21 (43.8%)	0.3902[2]
Male	6 (46.2%)	21 (60.0%)	27 (56.3%)	
Total	13	35	48	
Cause				
Chronic pain	7 (53.8%)	17 (48.6%)	24 (50.0%)	0.5427[3]
Sprain	5 (38.5%)	17 (48.6%)	22 (45.8%)	
After medial malleolus fracture	1 (7.7%)	1 (2.9%)	2 (4.2%)	
Total	13	35	48	

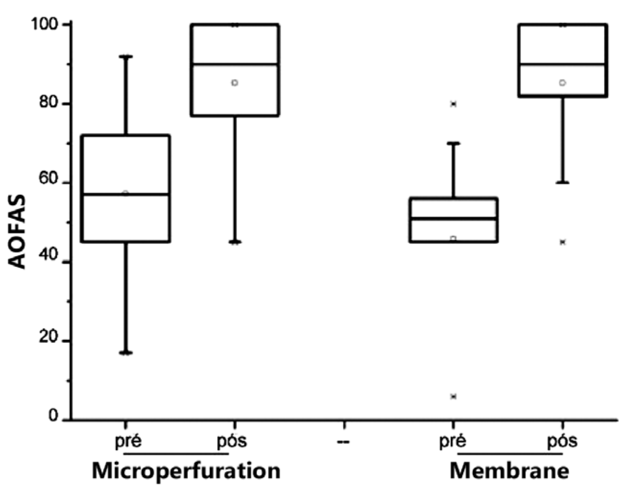
[1]Based on Mann-Whitney test; [2]Based on Chi-square test; [3]Based on Fisher's exact test; SD: Standard deviation; Min-Max: Minimum-Maximum.

Table 3. Descriptive analysis and AOFAS comparison between times and groups

Groups	Variables	n	Mean	SD	Minimum	Median	Maximum
Membrane	AOFAS Pre	13	45.8	± 2.6	6.0	51.0	80.0
	AOFAS Post	13	85.3	± 17.2	45.0	90.0	100.0
Microperfuration	AOFAS Pre	35	57.2	20.9	17.0	57.0	92.0
	AOFAS Post	35	85.3	15.4	45.0	90.0	100.0
Proteins (10%-35%)	05	1.7	8.1	± 1.47	290	98.3	18.1

ANOVA results for repeated measures with rank transformation	
Effect	**p-value**
Time	< 0.0001[1]
Group	0.2990
Time*group interaction	0.2194

[1]Significant increase in score after surgery, regardless of group. p-value = 0.1016 (Mann-Whitney): no significant difference in pre-measurement between groups à homogeneous groups. AOFAS: American Orthopedic Foot and Ankle Society; SD: Standard deviation.



Note: There was no difference between groups (p = 0.2990); only the effect of time was significant (p < 0.0001). Significant increase after group-independent surgery (ANOVA for repeated measures).

Figure 1. AOFAS score box-plot pre- and post-surgery in each group.

Table 4. Evaluation of the effect of age and lesion size on the AOFAS score before and after surgery

ANOVA results for repeated measures with rank transformation	
Effect	**valor-*p***
Time	0.0009[1]
Group	0.2715
Time*group interaction	0.0924
Time	0.0152[2]
Bigger size	0.7218
Time*group interaction	0.8749

[1]Significant increase in score after surgery, regardless of age; [2]Significant increase in score after surgery, regardless of lesion size. AOFAS: American Orthopedic Foot and Ankle Society.

Table 5. Descriptive analysis and AOFAS comparison between times and sex

Variables	n	Mean	SD	Minimum	Median	Maximum
Female						
AOFAS Pre	21	49.8	22.9	6.0	56.0	92.0
AOFAS Post	21	86.9	14.9	45.0	90.0	100.0
Male						
AOFAS Pre	27	57.5	20.5	17.0	55.0	90.0
AOFAS Post	27	84.1	16.5	45.0	90.0	100.0
p-value = 0.3600[1]						

ANOVA results for repeated measures with rank transformation	
Effect	**p-value**
Time	< 0.0001[2]
Sex	0.7267
Time*sex interaction	0.0933

[1] (Mann-Whitney) – no significant difference in the pre-measure between the sexes; [2] Significant increase in the score after surgery, regardless of sex. AOFAS: American Orthopedic Foot and Ankle Society; SD: Standard deviation.

Table 6. Descriptive analysis and AOFAS comparison between times and causes (sprain+fracture)

Variables	n	Mean	SD	Minimum	Median	Maximum
Chronic pain						
AOFAS Pre	24	56.0	20.7	9.0	56.0	92.0
AOFAS Post	24	84.9	15.3	45.0	88.5	100.0
Sprain+fracture						
AOFAS Pre	24	51.9	22.9	6.0	54.5	90.0
AOFAS Post	24	85.8	16.4	45.0	90.0	100.0
p-value = 0.4329[1]						

ANOVA results for repeated measures with rank transformation	
Effect	**p-value**
Time	< 0.0001[2]
Sex	0.6735
Time*cause interaction	0.2440

[1] (Mann-Whitney) - No significant difference in pre-measure between causes; [2] Significant increase in score after surgery regardless of cause. AOFAS: American Orthopedic Foot and Ankle Society; SD: Standard deviation.

seen. Between the groups, when size, sex, age, and underlying causes were compared, no results were found that added value to the comparisons. Improvement in each participant's symptoms, pain, and functionality was identified highlighting the importance of performing arthroscopy with bone marrow stimulation associated or not with the collagen matrix in the treatment of OTL.

The OTL is within the scope of the most common injuries found in the ankle after acute fractures. These findings collaborate in the indication and performance of post-trauma arthroscopy to identify intra-articular injuries[22]. Ischemic necrosis is among the most notorious identifiable causes of atraumatic lesions triggered by hormonal factors, hereditary conditions, or some constitutional change[3].

A study by Raikin et al.[5] found that lesions on the medial dome of the talus are more common than other quadrants and are also larger in surface area and depth. Currently, the parameters used for the surgical treatment of OTL consist of clinical symptoms, joint instability, lesion size with or without unstable fragments, and morphology.

In the group of non-invasive diagnostic methods, MRI showed higher sensitivity (0.96), and computed tomography showed higher specificity (0.99)[6]. Such tests, compared to physical examinations and radiographs, are superior and essential for detecting lesions and their correct treatment.

The comparison between bone marrow stimulation techniques and the application of collagen matrix membrane for treating OTL revealed significant improvement in AOFAS scores for both groups, with no statistically significant differences. The results of this study are supported by the work of Migliorini et al.[1], who found no significant differences between arthroscopic and mini-arthrotomy approaches for the implantation of autologous chondrocytes in the knee, suggesting that the method of surgical application may be less influential than postoperative management and patient-specific conditions.

Becher et al.[23] reiterate that after performing arthroscopic bone marrow stimulation with or without collagen types I and III matrix implantation, good clinical results were observed, with no significant differences identified in the lesions visualized by MRI. Using the collagen membrane, an approach supported by Jantzen et al.[16], showed promise in improving cartilage regeneration and postoperative management.

Although our study did not identify statistically significant differences between bone marrow stimulation techniques and the combination with collagen membrane in a short- to medium-term follow-up, Volz et al.[24], suggest that the addition of a collagen matrix may provide sustained clinical benefits over 10 years when compared to simple bone marrow stimulation. These findings underscore the importance of future investigations with long-term follow-up to assess whether the improvements observed in our study are maintained or diverge over time.

Among the limitations are the small sample size, absence of randomization, absence of descriptive data of intraoperative lesion sites, and difficulty obtaining imaging tests to prove lesion improvement. However, all difficulties did not prevent a positive result in the study.

Conclusion

This study confirmed the efficacy of both bone marrow stimulation techniques and collagen matrix membrane application in treating osteochondral lesions of the talus. The AOFAS score improved by a mean of 31.2 points, and both methods showed significant improvement. These results reinforce the existing literature, which suggests the feasibility of personalized approaches based on patient-specific conditions to optimize surgical outcomes.

Authors' contributions: Each author contributed individually and significantly to the development of this article: IOFG *(https://orcid.org/0009-0006-1323-3681), and RMRB *(https://orcid.org/0000-0002-0796-7148), and MMGDA *(https://orcid.org/0009-0006-4960-6398), and RGH *(https://orcid.org/0000-0003-3951-8408), and *HDB *(https://orcid.org/0000-0002-1901-3309) , and LPS *(https://orcid.org/0000-0003-4096-5563), and MSPC *(https://orcid.org/0000-0002-0758-2547) Conceived and planned the activity that led to the study, wrote the article, participated in the review process, data collection, bibliographic review, interpreted the results of the study. All authors read and approved the final manuscript.*ORCID (Open Researcher and Contributor ID) iD.

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Original Article

Effects of medializing calcaneal osteotomy associated with posterior tibial tendon re-tensioning in flexible flatfoot treatment in adolescents

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Abstract

Objective: Evaluate the correction of the talonavicular coverage incongruency angles after medializing calcaneal osteotomy associated with talonavicular capsuloplasty and posterior tibial tendon re-tensioning in 12 patients (14 feet) aged between 13 and 16 years.

Methods: A retrospective study, using medical records, analyzed radiographs in the anteroposterior incidence pre- and postoperative after six weeks of surgery. Patients submitted to the medializing calcaneal osteotomy associated with talonavicular capsuloplasty and posterior tibial tendon re-tensioning were included.

Results: The preoperative talonavicular coverage angle ranged from 15.49 degrees to 31.00 degrees with a mean of 26.02 degrees, and in the postoperative, after six weeks, there was a change in the talonavicular coverage angle ranging from 0.65 degrees to 10.69 degrees, with a mean of 05.56 degrees. In our evaluation, the p-values were < 0.0001, considered extremely significant. The talonavicular incongruency angle in the preoperative ranged from 35.00 degrees to 87.00 degrees, with a mean of 64.00 degrees, and in the postoperative ranged from 0.50 degrees to 19.80 degrees, with a mean of 8.65 degrees. In our evaluation, p-values were < 0.0001, considered statistically significant.

Conclusion: The results demonstrated statistically significant improvements in the correction of the talonavicular coverage and incongruency angles following medializing calcaneal osteotomy, associated with talonavicular capsuloplasty and posterior tibial tendon re-tensioning, in adolescents with symptomatic flexible flatfoot.

Level of evidence II; Prognostic studies - investigating the effect of a patient characteristic on the outcome of disease; Retrospective study.

Keywords: Flatfoot; Osteotomy; Foot deformity.

Introduction

Flexible flatfoot is a common condition, predominantly affecting children, characterized by the plantar arch collapse when the foot is bearing weight and its restoration when the load is removed. It is often associated with calcaneus valgus and may also involve forefoot abduction and supination relative to the midfoot[1,2]. One of the most accepted theories is that the plantar arch, because it is excessively flexible and associated with hypermobility of the subtalar joint, generates conditions that explain the plantar arch planning and the calcaneus valgus[3].

This foot pathology can occur alone or as part of a broader clinical change, such as neuromuscular diseases, genetic syndromes, collagen, and generalized ligament laxity[4].

Generally, the flexible flatfoot in the adolescent is painless, but in some cases, the pain can be present due to changes in its biomechanics, such as hindfoot valgus, forefoot abduction, and plantar arch collapse, causing the feeling of tiredness and

Study performed at the Department of Orthopedics and Traumatology,Hospital de Base de Sao Jose do Rio Preto, Funfarme/Famerp, Sao Jose do Rio Preto, SP, Brazil.

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pain when performing sports activities (Figure 1)[5]. It is known that Conservative treatment with orthoses featuring medial arch support, varus wedge, and pronation wedge is indicated when the patient reports pain in the territory of the posterior tibial tendon, despite producing good results regarding the pain, its use is not intended to correct the deformities of the foot[6]. Other conservative measures are strengthening the intrinsic and extrinsic foot muscles[7], losing body weight, stretching the calcaneal tendon, and temporarily reducing physical activities.

Surgical treatment may be indicated in painful feet after failure of conservative treatment, especially when there are radiographic changes, including a talonavicular angle exceeding 30%, a talonavicular uncovering angle greater than 7°, and alterations in the talonavicular incongruence angle[8]. Other important angles would be the calcaneal valgus angle above 16.00 degrees in the axial incidence, the increase of the Kite angle in the anteroposterior and standing orthostatic profile incidences, the change of the Meary angle in the lateral incidence and the increase of the Mereau Costa Bertani angle above 135.00 degrees[9].

In our study, bone correction was proposed using medializing calcaneal osteotomy, which consists of an oblique osteotomy at 45.00 degrees on the long axis of the calcaneus in profile, medializing the proximal fragment and decreasing the calcaneal valgus. It was also proposed talonavicular capsuloplasty associated with posterior tibial tendon re-tensioning[10].

The objective of the study is to evaluate the correction of the talonavicular coverage incongruency angles through anteroposterior radiographs of the feet after medializing calcaneal osteotomy associated with talonavicular capsuloplasty and posterior tibial tendon re-tensioning in 12 patients (14 feet) aged between 13 and 16 years.

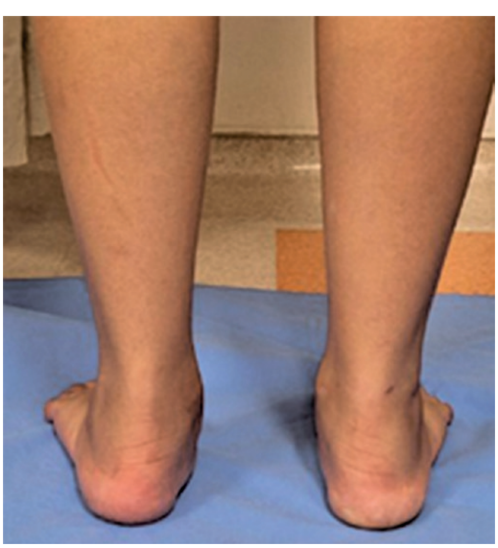

Figure 1. Clinical appearance of the patient showing hindfoot valgus.

Methods

This study was approved by the Institutional Review Board under the number 77477424.5.0000.5415.

This is a retrospective study performed on medical records through radiographs in the anteroposterior and profile incidences in the pre- and postoperative six weeks after the medializing calcaneal osteotomy procedure associated with talonavicular capsuloplasty and posterior tibial tendon re-tensioning. All medical record research was based on ethical values and data confidentiality.

Inclusion criteria were patients submitted to medializing calcaneal osteotomy associated with talonavicular capsuloplasty and posterior tibial tendon re-tensioning. All patients had closed calcaneal epiphyseal plates. Exclusion criteria were patients submitted to medializing calcaneal osteotomy associated with any other bone procedure, such as lateral column lengthening (Evans procedure) or medial cuneiform osteotomy to correct forefoot supination (Cotton procedure). There were no restrictions on sex. Patients with accessory tarsal and navicular coalitions were also excluded.

Surgical technique

With the patient in dorsal decubitus, a cushion was placed on the buttock ipsilateral to the surgery for elevation and internal rotation of the lower limb. Then, exsanguination and garroting of the limb were performed. To perform the medializing calcaneal osteotomy, an oblique incision was made immediately inferior to the fibular tendons on the lateral face of the calcaneus (Figure 2A), the sural nerve was visualized and removed (Figure 2B*)*. We sought to medialize the calcaneal fragment by approximately 1 cm. After this translation was obtained, the fragments were temporarily fixed with 2 Kirschner wires (Figure 2C) and permanently with two cannulated screws. For the posterior tibial tendon re-tensioning and talonavicular capsuloplasty, an incision was made in the medial surface of the foot (Figure 2D) towards the posterior tibial tendon to the navicular bone, where a number 4 anchor was inserted and assembled with two needles and wires using fiber wire type. A needle was used to advance the posterior tibial tendon, and with a second needle, talonavicular joint re-tensioning in its medial aspect was performed.

Radiographs evaluation

The talonavicular coverage and talonavicular incongruency angles were evaluated in the anteroposterior incidence. The talonavicular coverage angle was obtained through the lines formed by the lateral and medial points of the articular surface of the talus and navicular, with a mean value of 7.00 degrees (Figure 3A). The talonavicular incongruency angle was also obtained through the measurements drawn on the anteroposterior radiograph, using a line that joins the lateral extension of the articular surface of the talus (point a) and the lateral extension of the navicular surface (point c). A second

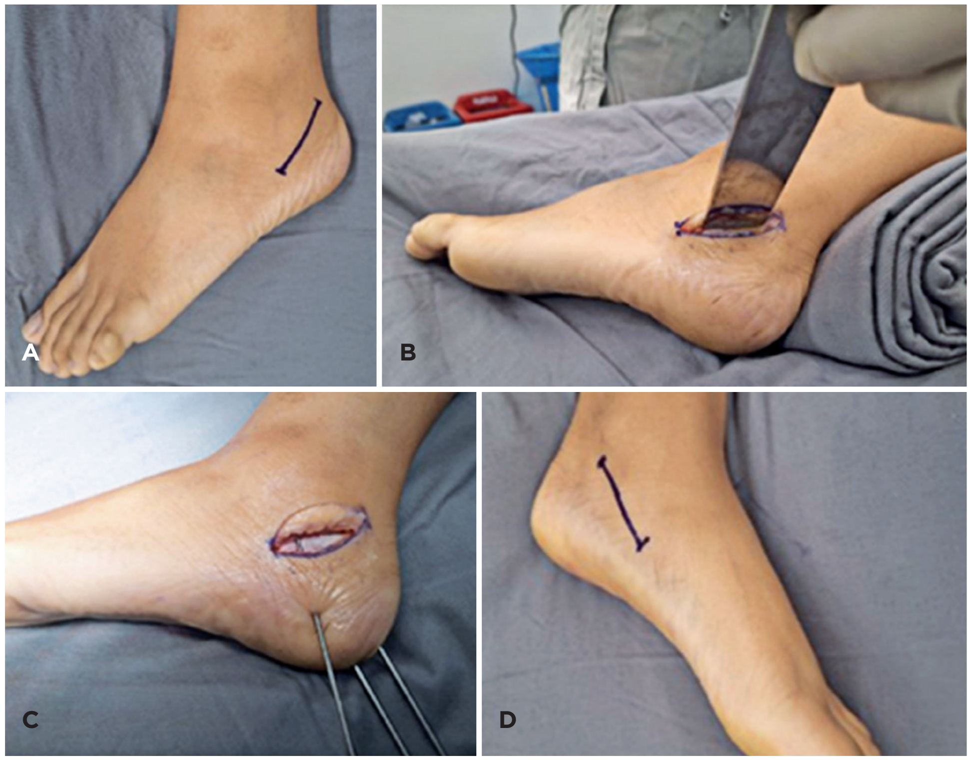

Figure 2. A) Marking of the lateral incision of the calcaneus, B) Calcaneal osteotomy, C) Temporarily fixation, D) Marking of the medial incision.

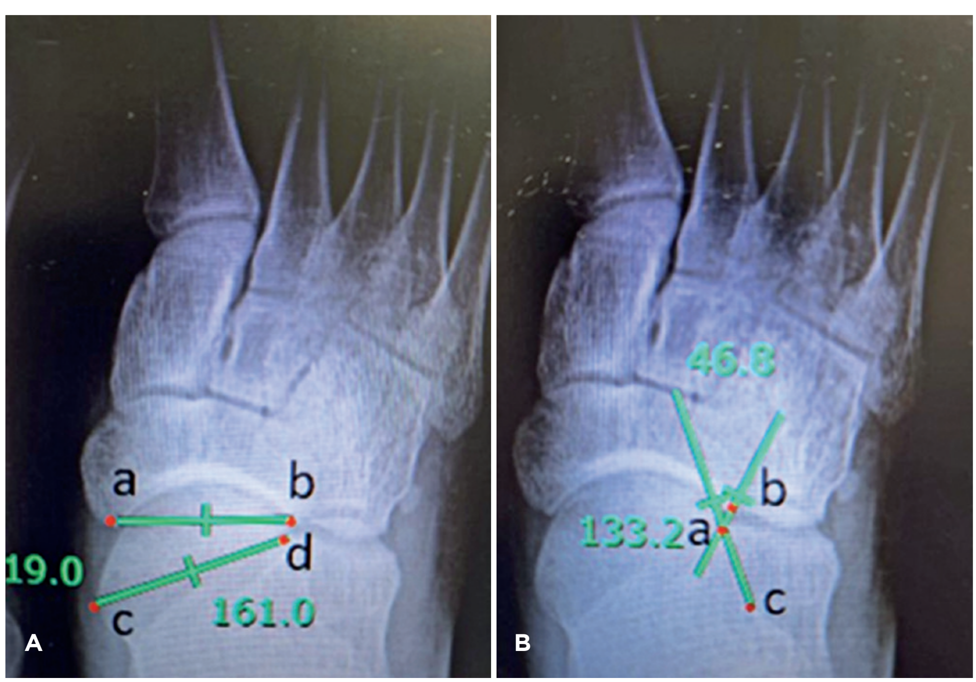

Figure 3. A) Talonavicular coverage angle on orthostatic anteroposterior radiography. B) Talonavicular incongruency angle on orthostatic anteroposterior radiography.

line was drawn between the lateral face of the talus neck in its narrowest segment (point b) and the lateral extension of the articular surface of the talus (point a). The incongruency angle between these two lines has a normality value ranging from 0 to 5.00 degrees, which changes when it exceeds this value (Figure 3B).

Statistical evaluation

After data collection, the analysis was conducted using an Excel spreadsheet. Descriptive statistical analysis included calculations of central tendency measures, dispersion, and frequency. For the inferential statistical analysis of quantitative variables, the Kolmogorov-Smirnov test was used to verify the data normality, and appropriate tests were applied to compare quantitative data. The Chi-square test and Fisher's exact test were used to compare frequencies.

Correlation analyses were performed using Pearson and Spearman correlation tests, depending on the nature of the data. The correlation coefficients (r) were classified as follows: r = 0.10 to 0.30 (weak), r = 0.40 to 0.60 (moderate), and r = 0.70 to 1 (strong).

In all analyses, p-value ≤ 0.05 was considered statistically significant. The programs used were Statistical Package For Social Sciences (SPSS, IBM, version 24.0), GraphPad Instat 3.10 (2009), and Prisma 6.07 (2015).

Results

From March 2020 to November 2023, 12 patients submitted to medializing calcaneal osteotomy associated with talonavicular capsuloplasty and posterior tibial tendon re-tensioning were selected, two patients with bilateral approach totaling 14 feet. Among the patients, 12 were male and four were female, aged between 13 and 16. Talonavicular coverage and incongruency angles were measured before and after six weeks (Table 1).

The XERO® program was used, all images were selected, and the measurement was performed by a single evaluator.

The talonavicular coverage angle before the surgical procedure ranged from 31.00 to 15.49 degrees, and the mean was 26.20 degrees; the talonavicular coverage angle after the procedure ranged from 10.69 to 0.65 degrees, and the mean was 5.56 degrees, in this evaluation the p-values were < 0.0001 considered extremely significant.

Discussion

The surgical indication for flexible flatfoot in adolescents is primarily based on the presence of symptoms, particularly when angular deformities of the foot are evident in anteroposterior and lateral incidences. The talonavicular coverage angle must be greater than 7.00 degrees per surgical indication criteria. According to Moraleda et al.[9] and Yan et al.,[11] several surgical techniques for the correction of deformities were reported, including arthroereisis, medializing calcaneal osteotomy, Evans osteotomy, Cotton osteotomy, and the association between osteotomies and soft tissue procedures[11]. In our study, the mean talonavicular coverage angle was 26.20 degrees, which is considered abnormal; in addition to pain, it serves as an indication for corrective surgery. After the medializing calcaneal osteotomy (Figures 4 and 5) associated with talonavicular capsuloplasty and posterior tibial re-tensioning, a mean of 5.56 degrees was obtained. Ghaznavi et al.[1], in a 100-foot study, identified a change with a mean of 13.90 degrees with 4.20 degrees of standard deviation in the talonavicular coverage angle before the medializing calcaneal osteotomy associated with

Table 1. Preoperative and postoperative angular values (in degrees)

Pacient	Sex	Age	Preoperative talonavicular coverage angle	Postperative talonavicular coverage angle	Preoperative talonavicular incongruency angle	Postperative talonavicular incongruency angle
1	M	12	31.00 degrees	3.72 degrees	47.60 degrees	15.00 degrees
2*	M	13	25.15 degrees	5.75 degrees	67.00 degrees	11.00 degrees
2*	M	13	28.78 degrees	10.69 degrees	48.00 degrees	10.00 degrees
3*	M	14	15.49 degrees	4.11 degrees	71.00 degrees	20.00 degrees
3*	M	14	26.20 degrees	6.08 degrees	68.00 degrees	13.00 degrees
4	F	13	24.88 degrees	5.20 degrees	87.00 degrees	0.50 degrees
5	M	12	29.35 degrees	3.06 degrees	57.90 degrees	5.40 degrees
6	F	15	16.15 degrees	5.11 degrees	61.80 degrees	5.40 degrees
7	M	12	19.21 degrees	7.77 degrees	67.70 degrees	9.50 degrees
8	F	13	19.65 degrees	5.75 degrees	35.00 degrees	3.30 degrees
9	M	13	30.72 degrees	5.56 degrees	41.70 degrees	3.00 degrees
10	M	13	28.52 degrees	0.65 degrees	85.50 degrees	6.00 degrees
11	M	14	29.30 degrees	5.75 degrees	81.30 degrees	19.80 degrees
12	M	14	21.50 degrees	4.48 degrees	77.70 degrees	12.20 degrees

*Patients with bilateral approach., n = 14.

posterior tibial re-tensioning, and mean of 5.70 degrees and 1.80 degrees of standard deviation after the procedure (Figure 6). According to the author, the normal angle is below 7.00 degrees; thus, the procedure was sufficient to return the angular normality[12]. Another angle analyzed in our study was the talonavicular incongruency angle, with a preoperative mean of 64.00 degrees. After the procedure, the angular mean increased to 8.65 degrees, with a statistically significant improvement; Deland[13] demonstrated that the use of the talonavicular congruency angle is a good measurement parameter for forefoot abduction in the adolescent's flexible flatfoot, a statement corroborated in the study by Ellis et al.[14]. In our study, 30 patients with flexible flatfoot were evaluated, the angular values ranged from 22.50 to 118.30 degrees with a mean of 70.40 degrees, before the procedure after the angular values ranged from 5.10 to 11.30 degrees, with a mean of 8.30 and 3.00 of standard deviation as the final result[15](Figure 7).

Conclusion

The results demonstrated statistically significant improvements in the correction of the talonavicular coverage

Figure 4. Lateral radiograph after medializing calcaneal osteotomy and posterior tibial tendon re-tensioning with an anchor inserted in the navicular.

Figure 6. Talonavicular coverage angle after six weeks of surgery.

Figure 5. Anteroposterior radiograph showing an anchor inserted in the navicular.

Figure 7. Talonavicular incongruency after six weeks of surgery.

and incongruency angles following medializing calcaneal osteotomy, associated with talonavicular capsuloplasty and posterior tibial tendon re-tensioning in adolescents with symptomatic flexible flatfoot.

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Original Article

Prospective study of the ankle inversion destabilization maneuver for acute ankle ligament injury

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Abstract

Objective: Present the result of a new maneuver for treating lateral ankle sprains.

Methods: A new technique for sensorimotor stimulation was incorporated into the conventional rehabilitation process of 100 patients with acute lateral ankle sprain with a 12-month follow-up. The primary outcome was new sprain episodes, and the secondary outcomes included quality of life (assessed by the Health Survey 12 questionnaire (SF-12)), pain (assessed by the Visual Analog Pain Scale (VAS)), function (assessed by the American Orthopaedics Foot & Ankle Society - Ankle-Hindfoot Scale - (AOFAS)) and patient-reported instability symptoms (assessed by the Cumberland Ankle Instability Tool (CAIT)).

Results: Among the patients included, a 12-month recurrence rate of new sprain episodes was observed at 6% (95% CI: 4.7%), which is statistically significant compared to the data reported in the literature. Regarding secondary outcomes, a statistically significant difference was observed among the onset, eight weeks, and 12 months in the AOFAS and CAIT scores. A statistically significant difference in the periods was also observed in VAS, with an initial mean of 5.94 to 1.29 at the end of treatment.

Conclusion: Based on our findings, a 12-month follow-up, the ankle inversion destabilization maneuver added to a standard rehabilitation protocol proved effective in preventing new lateral ankle sprain episodes.

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

Keywords: Joint instability; Rehabilitation; Ligaments; Physical therapy modalities.

Introduction

Ankle sprains are highly prevalent traumas in the population, especially in athletes[1]. It is estimated that there are about 5,000 sprains per day in the United Kingdom, while American data point to approximately 23,000 cases daily[2-3]. The literature worldwide has pointed out that about 7% to 10% of orthopedic care in an emergency service is due to ankle sprains, corresponding to about 25% of all musculoskeletal injuries and which can often cause injuries to the ligaments of the lateral ankle complex[4-6].

Despite the need to conduct higher-quality studies to prove its effectiveness, strategies such as cryotherapy, elevation, and compression of the ankle affected by a sprain seem to produce beneficial effects for patients, whether related to pain control or edema that affects the lower extremities[7,8].

Outlining a rehabilitation plan for lateral ankle sprains is currently a complex task. This complexity stems from flaws in many available studies, such as inadequate descriptions of patient selection criteria, safety measures, intervention effects, and training volume. These shortcomings make it challenging to create a treatment protocol comprehensively supported by high-quality literature. However, despite all the limitations, important directions in the available literature can be found[7,8].

Study performed at the Department of Orthopedics and Traumatology, Paulista School of Medicine – Federal University of São Paulo, SP, Brazil.

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Evidence found in the literature supports that patients undergoing exercise-based treatment protocols have a lower rate of new sprain episodes, a lower feeling of instability reported by the patient, and a greater reduction in pain in the long term[9].

Determining the volume of training as well as the total number of sessions that the patient should perform, based on the available literature, is not simple since studies with protocols ranging from 10 to 60 minutes per session with a total number of sessions that can vary from 5 to 84 sessions were found[10].

In their systematic literature review, Peterson et al.[11] showed sensorimotor strategies as efficient in preventing new sprain episodes, recommending their inclusion in rehabilitation programs[11]. Thus, it is understood that the development of techniques that aim to optimize the sensorimotor condition of the ankle contributes to the prevention of new lateral sprain episodes and consequently offers patients greater quality of life and safety. However, no specific maneuvers or techniques were found in the literature to address lateral ankle sprains, that is, maneuvers designed and conceived, considering anatomy and biomechanics of the ankle and its ligaments as well as trauma mechanisms, factors that are extremely important for the success of the rehabilitation process[11].

The objective of this study is to present the results of a new technique for sensorimotor training added to the conventional rehabilitation process of 100 patients with acute lateral ankle sprain, with a 12-month follow-up. The primary outcome was new sprain episodes, and the secondary outcomes included quality of life (assessed by the Health Survey 12 questionnaire (SF-12)), pain (assessed by the Visual Analog Pain Scale (VAS)), function (assessed by the American Orthopaedics Foot & Ankle Society - Ankle-Hindfoot Scale - (AOFAS)) and patient-reported instability symptoms (assessed by the Cumberland Ankle Instability Tool – (CAIT)). We hypothesize that the described technique of ankle inversion destabilization added to the conventional rehabilitation protocol decreases the rate of new lateral ankle sprain episodes compared to the data in the literature.

Methods

This study was approved by the Research Ethics Committee (approval number: CAAE 28126319.4.0000.5505) and all included patients signed the informed consent form. Individuals over 18 years of age, of both sexes, with a first episode of ankle sprain within 48 hours were included in the study. These cases involved complete or partial injury to any ligaments of the lateral ankle complex, which could present as isolated or associated ligament injuries.

Patients with a history of multiple ankle sprains (2 or more), previous surgery on the affected foot or ankle, previous complaint in the ankle region, any fracture associated with the sprain, or injuries that could in any way influence the application of the treatment protocol, any condition that represented any contraindication to the proposed therapies, as well as refusal by the patient to participate in the study were not included in the study. The study did not include patients with an impossibility or inability to sign the informed consent form.

Individuals with a history of ankle sprains who sought medical care in the emergency care units were consecutively allocated to the study and evaluated by the attending physicians. The evaluations consisted of a first interview, aiming to understand the factors associated with injury. The following data were collected for epidemiological analysis and interventions: sex, age, sprain site (medial, lateral, or combination), and sprain history (number of episodes). In a second moment, a clinical evaluation was performed, consisting of an inspection of the affected ankle and palpation in search of possible painful points indicative of osteo-ligamentous injuries. Subsequently, the patients underwent evaluation through radiographs with weight-bearing of the tibiotarsal joint of the ankle in three positions: anteroposterior (AP), lateral (P), and AP with internal rotation of 15º. Once the hypothesis of acute ankle ligament injury was confirmed, the patient was immobilized with an immobilizer boot for seven days, followed by a rigid side restraint orthosis for two weeks (worn with socks and sneakers) with weight-bearing as tolerated and removed only for bathing.

At the end of the first assessment, the patient was instructed to return to the rehabilitation outpatient clinic after seven days, where they immediately started the physiotherapy treatment, which included stretching, strengthening, and sensorimotor training exercises. The reversal destabilization maneuver was incorporated into the treatment at the beginning of the sixth week. Patients attended the rehabilitation outpatient clinic twice a week (until the eighth week), during which physiotherapy sessions were performed and clinical evaluation, totaling 16 sessions, with a minimum interval between sessions of three days and a maximum interval of four days. A new replenishment session was scheduled within the same week in case of a no-show. After this period, if they did not present pain symptoms or any other complaint related to the sprain or the treatment applied, they were discharged and returned in 12 months for reassessment.

All patients received a standard rehabilitation protocol for ankle sprain based on the current literature and described in detail in the Appendix 1. In the sixth week, the ankle inversion destabilization maneuver was introduced, so we set aside two weeks to work on the ankle stabilizing muscles and attenuate the deficits caused by immobilization, inherent to the use of immobilization and provide greater safety for the execution of the maneuver, first on stable ground. We evolved to unstable ground from the seventh week using a proprioceptive disc (Figure 1).

Patients were positioned barefoot in a standing position with the contralateral knee flexed, lifting the tested limb off the ground. A rigid elastic band was passed by the assistant physiotherapist from medial to lateral around the ankle to catch the two ends laterally to the ankle; then, the patient was asked to perform active ankle inversion that would be enhanced by the physiotherapist pulling the band.

The maneuver consisted of mild destabilizations in the anterolateral, laterolateral, and posterolateral planes (with enough force to cause stretching of the band without elastic distension), moderate (with enough force to cause a small elastic distension of the band), and intense (with enough force to cause large elastic distension of the band) being performed nine times in each plane alternating the intensity of the destabilization applied to the ankle through the elastic band starting from the most intense (in the initial phase of the movement) and evolving to the mildest (close to the maximum amplitude of the ankle inversion movement). The physiotherapist always started to perform the maneuver in the anterolateral plane by asking the patient for an active ankle inversion, requesting resistance to the movement, and returning to neutral when the physiotherapist applied tension. At the beginning of the movement, an intense destabilization was performed, with the patient bringing the ankle to the initial position.

The maneuver was then repeated this time when reaching about half of the inversion movement (about 20º), moderate tension was applied to the band, and the patient should resist and reposition his ankle in the initial position. Finally, the patient performed the inversion again. When approaching the total movement of the joint (about 40º), a slight tension was applied, with the patient repositioning his ankle again in the initial position. In this way, the cycle restarts until nine alternating repetitions are completed. A pause of about one minute was granted to the patient before performing the same maneuver on the next movement plane.

Figure 1. Movement worked on unstable and stable surface.

At the beginning of the seventh week after the sprain, if the patient did not present a worsening of the painful condition, the maneuver was started with the patient resting on the proprioceptive disc (unstable ground) following the same positions described above.

For patients with pain complaints, it was prescribed by the attending physician ketoprofen 100mg every 12 hours for three days. In cases of persistence of pain (VAS greater than or equal to 3), dipyrone 1g was prescribed every six hours.

Results

Between June 2020 and June 2022, 100 individuals were selected and included in our study: 49 men (49%) and 51 women (51%), 59 right ankles (59%), and 41 left ankles (41%) were evaluated. The mean age of the participants was 45 years (18-79 years), and 84.3% practiced physical activity regularly. As for the individuals who refused to participate in the study, they were treated with a standard protocol or referred to other physiotherapy services, according to the will expressed by each individual. Only patients who reported that was the first episode of a sprain were included. The mean time between the sprain onset and the evaluation was 18.9 hours. Regarding the mechanism of trauma, all patients presented sprains in ankle inversion, and 15% did not know what was the direction of the sprain, which ended up being elucidated later with clinical evaluation.

Nine patients (9%) had no edema at the initial physical examination. Of the patients with swollen ankles (91/100), 78 (78%) had greater edema on the lateral side, nine (9%) on the medial side and four (4%) on the anterior side. Regarding ecchymosis, 87 patients (87%) had no such alteration in the primary examination, two had anteromedial ecchymosis (2%), four anterolateral (4%), two medial (2%), two lateral (2%), two anterolateral (2%) and lateral and medial (2%). All patients underwent simple radiographic evaluation with weight-bearing, and none presented alteration. No patient experienced any adverse event secondary to physical examination or additional examinations.

Regarding the recurrence rate, as observed in Table 1, a rate of 6% (CI: 95%) was observed, being statistically significant ($p < 0.001$) when compared to the population without recurrence after treatment. No sprain or other adverse effect related to the execution of the destabilization maneuver was observed.

The full sample (All) was analyzed and segmented by group of new sprain episodes and sex. A statistically significant difference was found between the three periods in the All group and the subgroups. Thus, in all comparisons, the Wilcoxon test was used to compare the moments in pairs.

In the CAIT score, a statistical difference between the times was found in all segmentations. In the All group, the mean started at 16.54, went up to 26.22 at the end of treatment, and even more to 28.65 after 12 months (SD 2.95, CI: 0.58, p-value < 0.001) (Table 1). The AOFAS score showed statistical differences in all periods; the All group had the initial value of 41.67 and, at the end of 12 months, 98.38 (Table 2).

In the VAS score, a statistically significant difference was found in all segmentations. A reduction in values was always observed. In the All group, the mean started at 5.94, decreased to 1.29 at the end of treatment, and decreased to 0.35 after 12 months (SD: 0.41 CI: 0.08, p-value < 0.001) (Table 3).

In the SF-12 score, a statistically significant difference was found between the times, but in the subgroup with new sprain episodes, no difference between the onset was observed (with a mean of 24.33) compared to the 12-month mean of 24.17 (SD: 2.17, CI: 0.43, p-value = 0.43) (Table 4).

Discussion

Our study concentrated on patients who experienced an inversion sprain as their trauma mechanism, which accounted for 100% of the cases in our sample. The population had a mean age of 45 (18-79 years) with a sprain history in the last 48 hours.

Considering the primary outcome of our study (new sprain episodes), a possible reduction in the sprain index was observed when the inversion destabilization maneuver was added to the conventional rehabilitation protocol, findings that align with the literature since the most current studies on the prevention or even treatment of lateral ankle sprains

Table 1. Comparison between periods for CAIT score.

CAIT		Mean	Median	SD	Q1	Q3	N	CI	p-value
All	Start	16.54	14,5	9.25	7.75	26	100	1.81	**<0.001**
	End	26.22	27	3.75	23.75	30	100	0.73	
	12m	28.65	30	2.95	29	30	100	0.58	
No re-sprain	Start	16.99	15	9.33	7.25	26	94	1.89	**<0.001**
	End	26.24	27	3.76	24.25	30	94	0.76	
	12m	29.13	30	2.07	30	30	94	0.42	
With re-sprain	Start	9.50	8	3.21	8	11.75	6	2.57	**0.001**
	End	25.83	26	3.97	23.5	29.25	6	3.18	
	12m	21.17	20	4.58	19	24.75	6	3.66	
Women	Start	16.36	14	9.13	8	26	45	2.67	**<0.001**
	End	25.67	27	4.27	21	30	45	1.25	
	12m	28.78	30	2.88	29	30	45	0.84	
Men	Start	16.69	15	9.43	7	25	55	2.49	**<0.001**
	End	26.67	27	3.23	25	30	55	0.85	
	12m	28.55	30	3.02	29	30	55	0.80	

CAIT: Cumberland Ankle Instability Tool; SD: Standard deviation; CI: Confidence interval; 12m: 12 months.

Table 2. Comparison between periods for AOFAS score.

AOFAS		Mean	Median	SD	Q1	Q3	N	CI	p-value
All	Start	41.67	12	36.15	10	82	100	7.09	**<0.001**
	End	93.05	90	6.60	86	100	100	1.29	
	12m	98.38	100	4.71	100	100	100	0.92	
No re-sprain	Start	43.67	12	36.38	10	82	94	7.35	**<0.001**
	End	93.28	90	6.62	86	100	94	1.34	
	12m	99.36	100	2.46	100	100	94	0.50	
With re-sprain	Start	10.33	11	1.97	8.5	12	6	1.57	**0.002**
	End	89.50	88.5	5.61	85.5	90	6	4.49	
	12m	83.00	83.5	5.02	81.25	85	6	4.02	
Women	Start	39.29	12	35.70	10	82	45	10.43	**<0.001**
	End	91.82	90	7.06	85	100	45	2.06	
	12m	98.16	100	5.21	100	100	45	1.52	
Men	Start	43.62	12	36.73	10	82	55	9.71	**<0.001**
	End	94.05	90	6.09	90	100	55	1.61	
	12m	98.56	100	4.30	100	100	55	1.14	

AOFAS: The American Orthopaedic Foot & Ankle Society; SD: Standard deviation; CI: Confidence interval; 12m: 12 months.

point to sensorimotor training as one of the few strategies effectively capable of preventing new sprain episodes[11].

It also could be observed with the epidemiological data obtained, a higher incidence of lateral sprains in women (51%), data that aligns with the current literature that shows a higher incidence of these injuries in young women, exactly as described by Doherty et al.[12], who pointed out the female public as having an increased risk for ankle sprains[13].

Many are the modalities known in clinical practice to optimize the sensorimotor condition of the lower limb; however, in most of the studies, the lack of specific techniques for ankle stability was observed; that is, the focus of the interventions ends up being the lower limb as a whole and even the spine, structures that should undoubtedly be considered and addressed during the rehabilitation process of lateral ankle sprains. The maneuver described in this study is easy to reproduce since it requires only a proprioceptive disc and an elastic band, materials easily found in physiotherapy clinics, thus facilitating its insertion in rehabilitation programs and working together with other techniques[9,14,15].

Techniques with some action on ankle stability are available; among these, the Hop and Y-balance tests can be highlighted. This is a set of progressive maneuvers to evaluate functional limitations in the lower limb after injury to the anterior cruciate

Table 3. Comparison between periods for VAS score.

VAS		Mean	Median	SD	Q1	Q3	N	CI	p-value
All	Start	5.94	6.0	1.95	4.8	7.0	100	0.38	**<0.001**
	End	1.29	1.0	1.13	0.0	2.0	100	0.22	
	12m	0.35	0.0	0.88	0.0	0.0	100	0.17	
No re-sprain	Start	5.84	6.0	1.92	4.0	7.0	94	0.39	**<0.001**
	End	1.31	1.0	1.15	0.0	2.0	94	0.23	
	12m	0.18	0.0	0.41	0.0	0.0	94	0.08	
With re-sprain	Start	7.50	7.0	1.76	6.0	8.8	6	1.41	**0.002**
	End	1.00	1.0	0.89	0.3	1.8	6	0.72	
	12m	3.00	2.5	1.79	2.0	3.8	6	1.43	
Women	Start	6.11	6.0	1.98	5.0	8.0	45	0.58	**<0.001**
	End	1.36	1.0	1.03	0.0	2.0	45	0.30	
	12m	0.38	0.0	1.05	0.0	0.0	45	0.31	
Men	Start	5.80	6.0	1.93	4.0	7.0	55	0.51	**<0.001**
	End	1.24	1.0	1.22	0.0	2.0	55	0.32	
	12m	0.33	0.0	0.72	0.0	0.0	55	0.19	

VAS: Visual analog scale; SD: Standard deviation; CI: Confidence interval; 12m: 12 months.

Table 4. Comparison between periods for SF-12 score.

SF-12		Mean	Median	SD	Q1	Q3	N	CI	p-value
All	Start	24.20	25.5	3.49	21	27	100	0.68	**<0.001**
	End	27.49	28	1.93	26	29	100	0.38	
	12m	29.69	30	2.17	29	30	100	0.43	
No re-sprain	Start	24.19	26	3.50	21	27	94	0.71	**<0.001**
	End	27.51	28	1.96	26	29	94	0.40	
	12m	30.04	30	1.67	29	30.75	94	0.34	
With re-sprain	Start	24.33	24.5	3.61	24	25.75	6	2.89	**0.009**
	End	27.17	27	1.47	26.25	27	6	1.18	
	12m	24.17	24.5	1.72	24	25	6	1.38	
Women	Start	23.87	25	3.67	19	26	45	1.07	**<0.001**
	End	27.38	28	2.03	26	29	45	0.59	
	12m	29.67	30	2.00	29	30	45	0.58	
Men	Start	24.47	26	3.34	23	27	55	0.88	**<0.001**
	End	27.58	27	1.86	27	29	55	0.49	
	12m	29.71	30	2.32	29	30.5	55	0.61	

SF-12: Health Survey 12; SD: Standard deviation; CI: Confidence interval; 12m: 12 months.

ligament. However, rehabilitation professionals have also used lateral ankle instability as an integral part of sensorimotor training and discharge criteria for patients with lower limb alterations, unlike the technique of this study, which focuses exclusively on sensorimotor training of the ankle[9,14,15].

In a systematic literature review, Caldemeyer et al.[16] examined the literature for specific neuromuscular training protocols for women that could reduce the risk of new sprain episodes[16]. They included seven studies that combined 5,187 women who generally practiced basketball, volleyball, or football. When analyzing the table presented by the study with the description of the training, it can be observed that the protocols described are always focused on the neuromuscular control of the lower limb and spine, ranging from stable to unstable surfaces in addition to plyometrics and specific gestures of each sport without, however, focusing on the ankle joint and the multidirectional and biomechanical planes of this joint. The authors conclude that the results point to the effectiveness of neuromuscular training protocols in preventing sprain episodes.

In his study, Stasinopoulos observed the effectiveness of specific technical training, proprioceptive training, and orthosis in preventing sprain episodes in volleyball players. The proprioceptive training group followed a technique described by the author (balance chart) every day, 30 minutes daily throughout the season. His findings suggest all three preventive strategies were effective in athletes who suffered an ankle sprain only once or twice during their career. In athletes who suffered three ankle sprain episodes, technical training seemed more effective than the other two preventive methods. The use of orthosis proved effective in athletes who suffered an ankle sprain more than three times during their career. In this case, technical and proprioceptive training were equally effective in preventing further sprains[17].

Handoll et al.[18], in their Cochrane review, evaluated the effects of interventions used to prevent ligament injuries or ankle sprains in physically active individuals from adolescence to middle age. Five randomized trials with data from 3,954 participants were included. All trials involved young, active, mostly male adults participating in high-risk activities, usually sports. Except for ankle training on the disc, all prophylactic interventions involved the application of external ankle support in the form of semi-rigid orthosis, bandages, or high-top shoes. A significant reduction in ankle sprains can be observed in people who received external ankle support, and there is limited evidence of ankle sprain reduction for those with previous ankle sprains who did ankle disc training exercises. As previously described, the external stability provided by orthoses also has positive impacts on the prevention of new sprain episodes, which is why we use them as a transition between the immobilization period and advanced sensorimotor training since the ankle musculature is supposed to have decreased activity[18].

The main limitation of the maneuver described in this study is the absence of a device to accurately measure the ankle's angulation during execution, meaning the stimuli are applied approximately at the start, middle, and end of the movement. Additionally, the study's implementation at a single center limits external validity, and the absence of a randomized control group represents another limitation.

The main hypothesis of this study was confirmed: in 12 months, patients with ankle sprains had a lower rate of new ankle sprain episodes.

Conclusions

Based on our findings, a 12-month follow-up, the ankle inversion destabilization maneuver added to a standard rehabilitation protocol based on the current literature effectively prevented new lateral ankle sprain episodes after a first sprain. In addition, it positively impacts pain reduction, improved quality of life, and symptoms of ankle instability.

Authors' contributions: Each author contributed individually and significantly to the development of this article: DAOG *(https://orcid.org/0009-0003-9479-3629), and NSBM *(https://orcid.org/0000-0003-1067-727X) Conceived and planned the activity that led to the study, wrote the article, participated in the review process; GHCA *(https://orcid.org/0000-0002-6458-6317) Wrote the article, participated in the review process; TSM *(https://orcid.org/0000-0003-4168-0981) Interpreted the results of the study, participated in the review process; ACP *(https://orcid.org/0000-0003-3229-2063) Participated in the review process, formatting of the article. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Appendix 1. Post ankle sprain rehabilitation protocol

Post Ankle Sprain Rehabilitation Protocol
0-1 week
- Prevention of ankle flexion and inversion movements.
- Full-time immobilization in an immobilizer boot.
- Partial weight-bearing with axillary crutches bilaterally.
- Cryotherapy for pain and edema control performed twice a day for 20 minutes.
1-4 weeks
- Prevention of ankle flexion and inversion movements.
- Full-time immobilization in semi-rigid orthosis.
- Partial weight-bearing with axillary crutches unilaterally.
- Ankle everters strengthening.
- Ankle extenders strengthening.
- Isometric ankle flexors strengthening.
- Isometric ankle inverters strengthening.
- Posterior chain active-assisted stretching.
- Beginning of sensorimotor training.
- Removal of the semi-rigid orthosis (third week).
4-6 weeks
- Total weight-bearing without auxiliary crutches.
- Prevention of forced ankle inversion movement.
- Prevention of forced ankle flexion movement.
- Active ankle inverters strengthening, allowing only 10º of movement, evolving to 20º at the beginning of the sixth week.
- Active ankle flexors strengthening, allowing only 10º of movement, evolving to 20º at the beginning of the sixth week.
- Evolution of ankle sensorimotor training according to individual capacity.
- Maintenance and evolution of ankle everter strengthening.
- Maintenance and evolution of ankle extensor strengthening.
6-7 weeks
- Prevention of forced ankle inversion movement.
- Prevention of forced ankle flexion movement.
- Active ankle inverters strengthening, allowing only 20º of movement, evolving to 30º at the beginning of the sixth week.
- Maintenance and evolution of ankle everter strengthening.
- Active ankle flexors strengthening, allowing only 20º of movement, evolving to 30º at the beginning of the sixth week.
- Insertion of the ankle inversion destabilization maneuver on stable ground.
- Beginning of plyometric exercises.
7-8 weeks
- Insertion of the ankle inversion destabilization maneuver on unstable ground.
- Active ankle inverters strengthening in full motion.
- Active ankle flexors strengthening in full movement and a closed kinetic chain.
- Maintenance and evolution of ankle everter strengthening.
- Maintenance and evolution of ankle extensor strengthening.
- Maintenance and evolution of plyometric exercises.

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Original Article

Functional treatment of isolated stable Weber B fractures of the lateral malleolus with immediate weightbearing and joint mobilization

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Abstract

Objective: This study aimed to evaluate the clinical and radiographic outcomes of conservative treatment in patients with isolated Weber B fractures of the lateral malleolus.

Methods: Medical charts of 30 patients with isolated, stable Weber B fractures of the lateral malleolus with less than 2 mm of displacement were retrospectively evaluated. All patients underwent early weightbearing and joint mobilization, with treatment involving the use of a controlled ankle motion walker boot for a period of six to eight weeks. Clinically, qualitative variables such as the presence of residual pain, tibiotalar joint motion, and total return to physical activities were evaluated. Radiographic parameters included bone healing time, healing rate, and fracture displacement.

Results: Among the 30 patients, 6 (20%) experienced residual pain, while 25 (83%) successfully resumed their previous physical activities within an average period of 3.4 months. Limited joint mobility was observed in six (20%) patients. Radiographically, 22 (73.3%) patients had fracture deviation of 1 mm; 6 (20%) patients, of 2 mm; and 2 (6.7%) patients showed no deviation. Average time for bone healing was seven weeks. Three (10%) patients developed pseudarthrosis. Return to physical activities was correlated with time and rate for fracture healing. Residual pain was associated with pseudarthrosis, dyslipidemia, and hypothyroidism. Bone healing did not correlate with age, displacement, or comorbidities.

Conclusion: The present study demonstrated that the proposed conservative treatment yielded satisfactory clinical and radiographic results, with a high rate of bone healing and successful return to previous physical activities.

Level of Evidence IV; Retrospective case series.

Keywords: Ankle fractures; Conservative treatment; Treatment outcomes.

Introduction

Ankle fractures are common injuries encountered in daily practice, accounting for approximately 10% of all fractures. Among these, isolated trans-syndesmotic fibula fractures (type B) are the most prevalent[1]. Optimal treatment is basically determined by preservation of joint stability and congruency, which are maintained by both bony and ligamentous structures – most notably, the deltoid and syndesmotic ligaments[2]. A fracture is considered incongruent when fragment displacement exceeds 2 mm. Similarly, when the deltoid ligament is completely ruptured, the fracture is

Study performed at the Hospital do Servidor Público Municipal and Care Club, São Paulo, SP, Brazil.

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classified as unstable[3]. To assess stability, stress radiographs, including external rotation, single leg weightbearing, and gravity tests, are routinely performed. If the fracture is stable, non-operative treatment can yield good to excellent long-term outcomes in terms of pain and function[4,5,6].

The most commonly used immobilization methods for non-surgical treatment include casts and orthoses as the controlled ankle motion walker boot (CWB)[7]. For some time, plaster cast immobilization without weightbearing on the affected limb was the standard treatment. However, the absence of joint loading and mobilization increases the risk of complications, such as leg muscle atrophy, joint stiffness, and deep vein thrombosis[8,9,10]. Long-term consequences can occur, such as persistent calf muscle weakness, gait abnormalities, and complex regional pain syndrome[11]. However, there is limited information on whether functional protocols involving removable orthoses and early joint mobilization may be associated with adverse events[12].

The aim of this study was to evaluate the clinical and radiographic outcomes of a group of patients with acute, stable, isolated Weber B fracture of the lateral malleolus (displacement of less than 2 mm) treated with a CWB and early weightbearing and joint mobilization. A secondary objective was to assess the correlation between clinical variables and radiographic findings.

Methods

Study design and studied population

This is a retrospective study involving a series of patients with acute, stable Weber B fractures of the lateral malleolus with less than 2 mm of displacement and treated non-surgically with early weightbearing and joint mobilization. The study was conducted at a single center, from January 2016 to July 2022 and approved by the Institutional review board (IRB) under the number 71256023.8.0000.5442. All patients had their first appointment with a foot and ankle specialist within one week of the trauma. Of the 52 ankle fractures treated during the described period, a total of 30 patients met the inclusion and exclusion criteria. Mean age of patients was 53.83 (range, 30–80) years. Fourteen (47%) patients were female, and 16 (53%) patients were male. During the visit, they were initially evaluated for deltoid ligament injury (Figure 1). If medial pain and/or edema was present, a rotation stress view was obtained to assess fracture stability, focusing on the widening of the medial clear space and on the position of the distal fragment of the malleolar fracture (Figure 2). Where the clear medial space widening was less than 4 mm, non-surgical functional treatment was indicated. Where the widening exceeded 4 mm, surgical treatment was indicated. In the absence of pain and swelling on the medial side, conservative treatment was indicated. Literature has reported that these findings suggest the deltoid ligament is either intact or partially ruptured, rather than completely torn[13]. The functional protocol consisted of the use of a CWB and immediate joint mobilization for a period of six to eight weeks. Patients were instructed to perform daily plantar flexion and ankle extension exercises, with weightbearing on the CWB allowed as tolerated. The CWB removal was allowed during sleep. All patients were treated by two trained, experienced foot and ankle surgeons. Routine serial radiographs were taken at two and six weeks of treatment and, in some cases, at eight weeks, depending on the progression of bone healing. The study enrolled patients aged 18 years and older with stable Weber B lateral malleolus fractures with less than 2 mm of displacement. Exclusion criteria included a history of prior ankle surgery, bilateral fractures, bimalleolar and trimalleolar fractures, smoking habits, and comorbidities such as diabetes mellitus and inflammatory arthropathies.

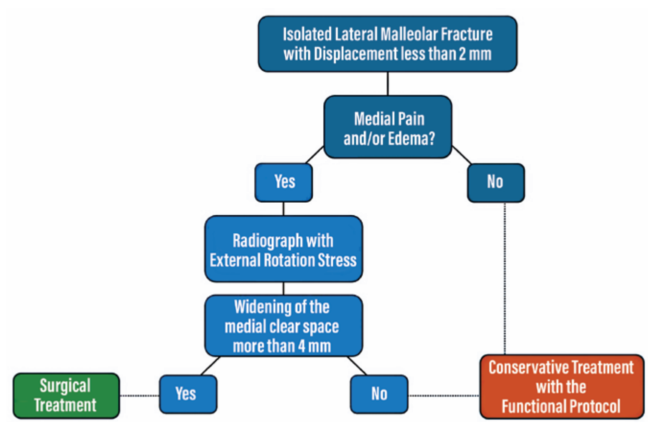

Figure 1. Flowchart for treatment decision.

Figure 2. Evaluation of joint stability with stress test in external rotation. (A) radiographic view at rest and (B) under stress.

Clinical and radiographic variables

Clinical data for the study were obtained through a retrospective review of medical records. For clinical evaluation, qualitative variables, such as the presence of any residual pain on physical examination or patient-reported complaint, range of motion (ROM) of the tibiotalar joint compared with the contralateral side, mainly extension restrictions, and complete return to physical activities, were assessed. All patients engaged in recreational activities, most commonly gym workouts, walking, running, and soccer. Radiographic parameters included bone healing time, fracture displacement, and progression to pseudoarthrosis. Fracture nonunion was confirmed by computed tomography images obtained six months after the trauma. Radiographic data and measurements were obtained using the Vue Motion software (Carestream Health, Rochester, NY, USA).

Statistical analysis

For statistical analysis, a convenience sample (non-probabilistic) comprising all patients treated during the specified period who met the inclusion and exclusion criteria was used. We evaluated the correlation between qualitative clinical variables and healing time, fracture displacement, age, and comorbidities. Additionally, the relationship between consolidation time and fracture displacement, age, and comorbidities were also assessed. Pearson and Spearman correlation tests were applied, with all statistical analysis conducted using JASP software version 0.16.2. A p-value of less than 0.05 was considered statistically significant.

Results

At an average follow-up of 4.24 (range 4–9) months, 6 (20%) patients reported residual pain and 25 (83%) patients had returned to their previous physical activities within an average of 3.4 (range, 2–8) months. Some limitation in ROM was observed in six (20%) patients on physical examination. Regarding comorbidities, 11 (37%) patients had hypertension, 4 (13%) patients had dyslipidemia, and 4 (13%) patients had hypothyroidism (Table 1). Radiographically, 22 (73.3%) patients had a fracture displacement of approximately 1 mm, 6 (20%) patients had a displacement of 2 mm, and 2 (6.7%) patients showed no displacement. The average bone healing time was seven (range, 5–12) weeks. Three (10%) patients developed pseudarthrosis and underwent surgical treatment (Table 2). None of the patients without medial pain or edema experienced further fracture displacement during treatment.

The return to physical activities was correlated with the time required for fracture healing and the presence of pseudarthrosis, indicating that a longer healing period directly affected the duration of physical activity suspension. Patients with pseudoarthrosis were unable to resume physical activities. No correlation was found between ankle ROM limitation and the time to return to activity. Residual pain was correlated with pseudarthrosis, dyslipidemia, and hypothyroidism. However, the time to union showed no correlation with age, fracture displacement, or comorbidities (Table 3).

Discussion

Malleolar fractures at the level of the distal tibiofibular syndesmosis are common injuries and can be effectively managed through conservative or surgical treatment, depending on joint stability and congruency[6]. Additionally, previous guidelines strongly recommend functional treatment and weightbearing as soon as tolerated[14,15]. Our study demonstrated that conservative treatment of isolated Weber B lateral malleolar fractures using a functional approach, with

Table 1. Demographic data and clinical outcomes

Patients	Age	Gender	RPA	TRPA (months)	Residual Pain	ROM Limitation	Comorbidities
30	53.83 (range, 30–80)	14 F:16 M	25 (83%)	3.4 (range, 2–8)	6 (20%)	6 (20%)	19 (53%)

RPA: return to physical activities; TRPA: time to return to physical activities; ROM: range of motion.

Table 2. Radiographic data and outcomes

Patients	Without displacement	1 mm displacement	2 mm displacement	Bone healing (weeks)	Pseudoarthrosis
30	2 (6.7%)	22 (73.3%)	6 (20%)	7 (range, 5–12)	3 (10%)

Table 3. Correlation between Clinical and Radiographic Variables

	Displacement	Age	Gender	Healing time	Residual pain	Range of motion	Pseudoarthrosis	Hypertension	Dyslipidemia	Hypothyroidism
Return to physical activities	0.48	0.75	0.15	0.005*	0.65	0.02	0.001*	0.69	0.18	0.68
Range of motion	0.29	0.98	0.29	0.17	0.87	X	0.56	0.20	0.30	1.0
Residual pain	0.29	0.22	0.86	0.09	X	0.83	0.034*	0.59	0.002*	0.013*
Healing time	0.61	0.76	0.146	X	x	X	x	0.60	0.36	1.0

Pearson and Spearman correlation tests.
*Statistical significance when p < 0.05.

immediate weightbearing and early joint mobilization, yields satisfactory results, with an 83% rate of return to previous physical activities and a 90% rate of bone consolidation.

Conservative treatment options for stable lateral malleolar fractures have been reported with varying protocols regarding types and duration of immobilization, as well as timing for initiating weightbearing and joint mobilization. Overall, studies have demonstrated satisfactory results, but they primarily consist of case series and comparative assessment involving plaster cast, functional bracing, CWB, and customized shoes[16]. Functional treatments with early weightbearing have shown to be safe and effective, yielding better clinical scores compared to traditional cast immobilization[17]. Brink et al.[8] conducted a study comparing the use of an ankle brace with a CWB in 66 patients, evenly divided into two groups. They found that both dynamic braces provided good pain relief within four weeks and allowed for a return to work by six weeks. All fractures showed union at 12 weeks of radiographic follow-up. However, the CWB group experienced greater pain relief, increased ROM, and an earlier return to ambulation[8]. van den Berg et al.[18] compared functional treatment using a removable brace with cast immobilization in a group of 44 patients with stable type B fracture. All patients initiated weightbearing one week after the fracture. At the 52-week follow-up, clinical and functional outcomes were similar between the two groups. However, the brace group showed a wider ROM[18]. Zeegers et al.[19] applied a stabilizing shoe, designed for functional treatment, following surgical treatment in a group of 24 patients with fractures of the lateral malleolus, intact deltoid ligaments, and fragment displacement of less than 2 mm. It consisted of a laced shoe that allowed flexion and extension of the tibiotalar joint, but featured lateral reinforcement to prevent supination, pronation, eversion, and inversion of the foot. At the final follow-up, 11 of the 13 active patients had returned to their previous physical activities, 7 (29%) patients reported residual pain, and there was no relevant reduction in ankle ROM[19]. Compared to the studies mentioned above, our patients were likely less immobilized, wearing the CWB only while walking. They were permitted to remove it during sleep and periods of rest. With the applied protocol, most patients returned to their pre-injury activity levels within an average of 3.4 months, with only a few reporting residual pain and limitations in ROM.

When treating ankle fractures nonsurgically, stability is a key concern. On initial radiographs, stable supination-external rotation stage II fractures, according to the Lauge-Hansen classification, may appear identical to unstable stage IV fractures. Therefore, it is paramount to accurately assess joint stability before proceeding with the functional conservative treatment[20]. Clinical signs like medial pain and ecchymosis are unreliable, as they do not necessarily indicate a complete rupture of the deltoid ligament[21]. Different stress radiographic tests, including external rotation, gravity, and weightbearing, have been described. However, systematic reviews and meta-analyses have not yet determined the most effective test[22,23,24,25]. In this study, patients with medial symptoms underwent external rotation test, which was performed by one of the two foot and ankle surgeons responsible for their treatment.

When the treatment approach is appropriately chosen based on fracture stability, both conservative and surgical treatment for stable Weber B ankle fractures can yield comparable clinical and functional outcomes[26,27,28,29]. Laurence et al.[29] assessed a cohort of 49 patients with Weber B fractures, with 20 patients receiving operative treatment and 29, undergoing conservative management. The mean follow-up periods were 6.9 years and 6.7 years, respectively. The non-operative group scored better on four clinical and functional questionnaires[29]. Overall, most systematic reviews and meta-analyses indicate that, while outcomes of both treatments were comparable, clinical complication rates were lower for the conservative approach[30,31]. Regarding bone healing, Willett conducted a study involving 620 patients who were randomly assigned to either a surgical or non-surgical treatment group. In the surgical group, no cases of non-union were observed, while the non-surgical group reported a 2.9% incidence of non-union. Although our non-union rate was higher, it is important to consider that this rate may be overestimated due to the smaller sample size in our study[32].

Although our study is not the first to evaluate the functional treatment of stable Weber B fractures using CWB, it is among a few studies correlating clinical and radiographic variables, including those related to return to physical activities. Additionally, we detailed a protocol that allowed patients to mobilize the ankle joint daily and sleep without the boot.

The study has limitations, including its retrospective design and small sample size. Despite these constraints, statistically significant correlations were found between clinical and radiographic variables. Another limitation is the absence of a control group to compare our results with other types of immobilizations, different joint mobilization protocols, and varying weightbearing periods. Additionally, the clinical variables analyzed were qualitative, and we did not quantitatively measured ROM and functional outcomes. Nevertheless, positive correlations between clinical and radiographic variables were observed, which may be relevant for daily medical practice. Moreover, patients studied also exhibited heterogeneity in age and levels of physical activity.

The study demonstrated that the proposed treatment yielded satisfactory clinical and radiographic results, with a high rate of bone healing and return to pre-injury physical activities. However, further prospective studies with larger populations are necessary to more comprehensively evaluate the conservative treatment of stable Weber B ankle fractures. Comparing different functional treatment protocols will help establish clearer guidelines for optimal clinical and radiographic outcomes.

Author's Contribution: Each author personally and significantly contributed towards the development of this article: DRCN *(https://orcid.org/0000-0003-0227-2440) Conceived and planned the activities that led to the study, interpreted the results of the study, wrote the paper, participated in the reviewing process; FAD *(https://orcid.org/000-0001-6871-2491) Conceived and planned the activities that led to the study, interpreted the results of the study, wrote the paper, participated in the reviewing process; ESS *(https://orcid.org/0009-0006-0087-1983) Conceived and planned the activities that led to the study, wrote the paper, participated in the reviewing process; VS *(https://orcid.org/0009-0009-7097-4090) Conceived and planned the activities that led to the study, wrote the paper, participated in the reviewing process; PAP *(https://orcid.org/0000-0001-9667-0006) Participated in the reviewing process; FCPF *(https://orcid.org/0000-0002-8907-0472) Interpreted the results of the study, participated in the reviewing process; BRM *(https://orcid.org/0000-0002-5306-2972) Interpreted the results of the study, participated in the reviewing process; AAMM *(https://orcid.org/0000-0002-2818-9939) Interpreted the results of the study, participated in the reviewing process; MPP *(https://orcid.org/0000-0003-0325-8050) Interpreted the results of the study, participated in the reviewing process. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Original Article

Non-surgical treatment of hallux valgus: practices of Brazilian foot and ankle specialists

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Abstract

Objective: This study aims to analyze how foot and ankle specialists in Brazil approach hallux valgus conservatively.

Methods: An online questionnaire on conservative treatment of hallux valgus was used to evaluate the practices adopted. Results were analyzed, and proportions were calculated to determine if there is a common treatment pattern or variations among specialists.

Results: There is a clear preference among Brazilian foot and ankle specialists regarding conservative treatment. Primary emphasis is placed on footwear adjustment and lifestyle modification, followed by the use of silicone protectors. The utilization of custom-made and prefabricated orthoses is less common compared to the preference for these methods among specialists worldwide. The literature tends to indicate that non-surgical methods primarily provide symptomatic relief to patients, with a negligible delay in the comorbidity progression.

Conclusion: For those opting for conservative treatment, there is a consensus in Brazil regarding the change of footwear and lifestyle, aligning with the preference of experts worldwide.

Level of Evidence III; Retrospective comparative study.

Keywords: Foot Deformities; Hallux Valgus; Conservative Treatment; Orthopedics.

Introduction

Hallux valgus (HV) is a complex, three-dimensional deformity that affects the general population and has a high prevalence in adults over 65 years old, affecting about 33% of these individuals. This deformity can cause pain and functional limitations, affecting the patient's gait[1-4]. Due to the deformity and alterations in gait, there is a predisposition to falls, loss of stability, and muscle weakness, with a decrease in quality of life. This negatively impacts various areas and may potentially trigger other injuries due to the increased risk of falls[5-8].

The number of HV surgeries performed in the United States increased by approximately 70% between 1994 and 2010, reaching over 400,000 procedures per year. This figure may be even higher, as there are no recent data available[7].

Treatment of HV can be carried out through surgical or conservative means, and often both techniques are used together to optimize patient recovery. When managing HV conservatively, foot and ankle specialists have a wide range of options to conduct treatment, ranging from wearing appropriate footwear to treatments with ultrasound. However, there is a limitation regarding scientific evidence to guide the

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

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conservative treatment of HV, mainly due to a lack of strong evidence-based studies about it.

Certain scholars rationalize the dearth of studies with robust evidence by attributing it to the inherent difficulty in ascertaining whether patients genuinely adhered appropriately to the guidelines in the conservative treatment of HV[1,3,5,6,8,9].

Several studies assessed the preferences of specialists regarding conservative treatment of HV[1-5]. However, there is no data in the literature pointing to the most adopted choices among specialists in Brazil. Additionally, there is a lack of robust evidence on the most effective approaches to address HV. For these reasons, the aim of this study was to investigate how HV is non-surgically treated in Brazil.

Methods

This is a cross-sectional survey study done through an online questionnaire completed in February of 2023. All foot and ankle specialists affiliated with the Brazilian Association of Medicine and Surgery of the Ankle and Foot (ABTPé) received a link to answer the questionnaire either by email and/or WhatsApp. All participants signed an informed consent form prior to getting to the questions. The questionnaire completion was voluntary and did not result in any benefit or harm to respondents. Ethical approval was granted by our institution ethical committee.

Survey instrument

The questionnaire was prepared based on an Australian study and adapted to the Brazilian reality[1]. It was completed anonymously by respondents on the Google Forms© platform. Collected data were then exported to Microsoft Excel and converted into graphics for better explanation.

The questionnaire comprised 16 questions, wherein participants were queried about their age and years of experience in the field of foot and ankle specialization. Additionally, it sought insights into the average annual volume of HV cases operated upon by participants and the predominant surgical techniques employed. It encompassed questions related to preferences for conservative treatment modalities and others into the personal success rates associated with the techniques applied. The full questionnaire is available in Appendix 1 – Questionnaire.

Statistical analysis

Research results were entered into an Excel spreadsheet, where corresponding graphs and their respective percentages were generated. For questions where it was possible to select more than one choice, responses were separated individually to make it clear how many specialists out of the total number of respondents marked a specific alternative.

Results

The questionnaire was dispatched to 733 members of ABTPé. A total of 90 participants engaged in the survey, wherein 89 conscientiously addressed all questions, while one participant refrained from completing the questionnaire in its entirety. Most experts who participated in the study fell within the age range of 30 to 51 years.

More than two-thirds (67%) of participants prescribe some form of non-surgical treatment for HV. Among those who choose not to pursue any conservative treatment, the primary justifications are the lack of solid evidence supporting the effectiveness of conservative treatment for HV (37.5%) and the personal perception of inefficacy of non-surgical treatments (37.5%).

As shown in Figure 1, 18.8% of participants argued that HV is inherently a surgically treated condition and that they do not achieve favorable results with conservative treatment. Only 9.4% of participants cited patient refusal of non-surgical treatments for this comorbidity as justification.

For those specialists who opt for conservative treatment, this research demonstrates that 56.7% of them do not achieve satisfactory results. The questionnaire also indicates that the most common rationale for prescribing conservative treatment is the belief that non-surgical treatment can benefit the patient (50.8%), followed by direct patient requests to try something before surgery (49.2%). In this group, most professionals (54.1%) choose to recommend non-surgical treatment 30 to 90 days before surgery, while 34.4% of them opt for it 90 to 180 days before surgery.

Sixty-eight specialists answered the questions regarding their preferred methods for preoperative conservative treatment of HV. Among the most frequently utilized methods, footwear modification stands out as the primary choice (66,97%). This is followed by lifestyle adjustments (54.4%). Additionally, only 2.9% of participants prescribe injectable medications, and none recommended custom-made foot orthoses (Figure 2).

In the postoperative period, 85.6% of specialists recommend some form of physical therapy. Those who do not follow justify their decision by either not perceiving the benefits of

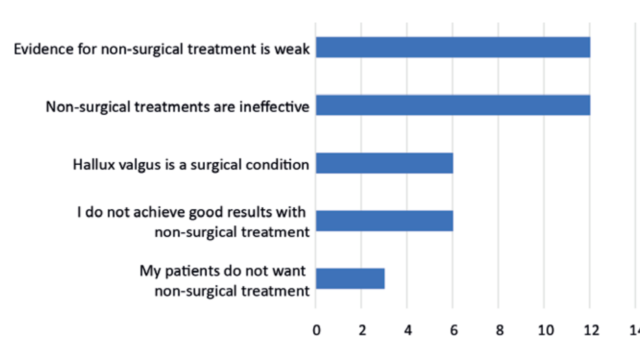

Figure 1. Reasons for not recommending conservative treatment for hallux valgus.

physical therapy after surgical treatment (66%) or expressing concern that physical therapy might negatively impact surgical outcomes (33.3%).

Among the 85.6% of participants who recommend postoperative physical therapy, 71.8% claim to achieve better results with the assistance of a physical therapist, and 61.5% of them report always prescribing physical therapy after all surgical procedures. The research suggests that 32.1% of participants opt to indicate physical therapy after the fourth postoperative week, while 25.6% of them start it after the second postoperative week.

The majority (55.1%) of participants continue physical therapy for four to eight weeks in the postoperative period. Ninety-eight percent of study participants reported positive outcomes with the physical therapist's routine follow-up after surgical treatment for HV.

Regarding preferences for postoperative physical therapy for HV, 58% of specialists recommend specific "foot core" strengthening, 74% advise scar tissue release and overall muscle strengthening of the patient's foot, 70.1% endorse stretching sessions, and 55.8% suggest lymphatic drainage. Only 5.2% of participants prescribe treatment with bandages (Figure 3).

Out of the 89 respondents who completed the questionnaire appropriately, 42.7% perform 10 to 30 surgical procedures for HV per year, followed by 36% who handle 30 to 50 cases annually (Figure 4).

The present survey of Brazilian specialists highlights the varied approaches to the surgical and conservative management of HV, as demonstrated in Figure 5. While preferences for conservative and postoperative treatments are well-documented in this study, further research is needed to understand how the complexity and severity of cases influence the choice of surgical techniques.

Discussion

This study is the first to investigate the practice of Brazilian foot and ankle specialists regarding HV conservative treatment. The most commonly employed surgical technique among Brazilian specialists is the chevron procedure, followed by percutaneous techniques. These results align with the general preference among Swiss orthopedists[10,11].

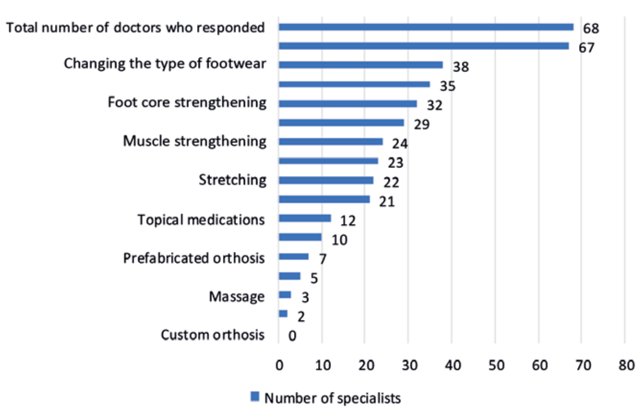

Figure 2. Personal preferences in conservative treatment.

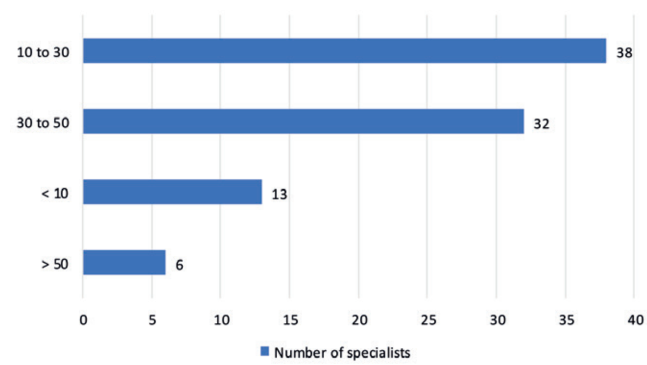

Figure 4. Number of hallux valgus surgeries per year.

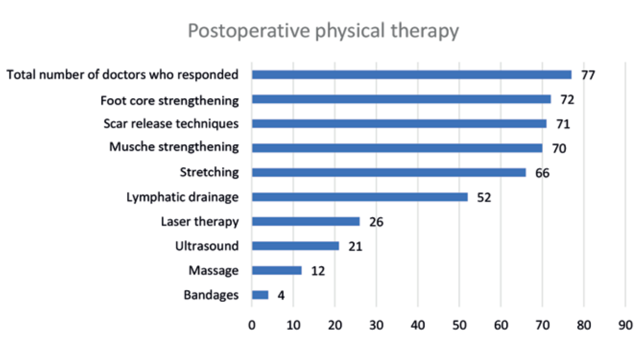

Figure 3. Personal preferences in postoperative physical therapy.

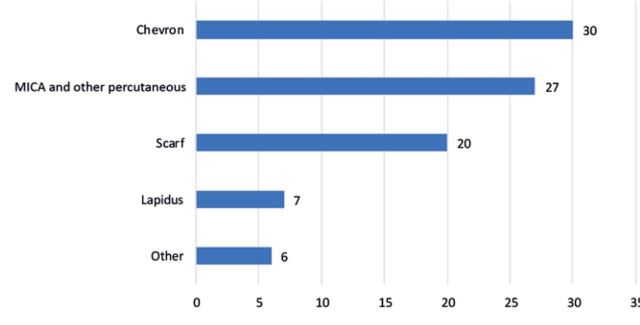

Figure 5. Surgical techniques used by Brazilian specialists.

The most recommended type of conservative treatment is a change in footwear, recommended by 97% of specialists who participated in the research; followed by lifestyle changes, ranging from physical activity to the time spent in an upright position. This aligns with findings emanating from global research endeavors[9-12].

Stretching exercises are often suggested (32%), while massages are rarely prescribed by the Brazilian community (4.4%). The use of silicone protectors (42%) and the strengthening of the foot core (47%) are also frequently prescribed by Brazilian specialists. German orthopedic practitioners extensively employ silicone protectors and toe separators[11]. The use of oral medication such as nonsteroidal anti-inflammatory drugs has a significant prevalence in the Brazilian community (33%). In contrast, the utilization of injectable medications is minimal (2.9%), despite this treatment modality being widely embraced in other nations[9,11,12]. The use of prefabricated orthoses (10%) and custom orthoses (0%) is not very common in Brazil, as well as the prescription of night orthoses (14%)[13].

A noticeable discrepancy in the use of orthoses for the non-surgical treatment of HV can be observed between Australian and Brazilian specialists. Hurn et al.[1] demonstrated a high recommendation for customized and prefabricated orthoses. The study also highlighted the high prevalence of lifestyle changes recommended for conservative HV treatment. This difference may be explained by the fact that many Brazilian foot and ankle specialists do not perceive substantial efficacy in non-surgical treatment. Despite a high prescription rate of conservative treatment (67%), most professionals do not report good results (56%)[1,14-16].

Several studies suggest that the use of rigid orthoses, such as toe separators, may provide swift relief for HV symptoms but does not improve pre-existing deformities significantly, exerting limited influence on the comorbidity progression. Conversely, physical therapy emphasizing foot core strengthening demonstrates more promising indications in delaying disease progression, albeit with a slower onset of symptom relief. The study concludes that combining orthoses with foot core strengthening offers superior prospects for retarding deformity progression and provides more rapid relief for HV symptoms[9,11,12,15].

The study conducted by Reina, in 2013, demonstrates there were no significant structural changes observed in the condition in patients using orthoses compared to those who did not use them. This finding corroborates the hypothesis proposed by other authors. This information may be utilized to justify the lesser prescription of non-surgical treatment as the primary therapeutic approach for HV[17].

The questionnaire also reveals a high (85%) prescription of physical therapy in the postoperative period. This is justified by the fact that the majority (71%) of professionals note better postoperative outcomes with the assistance of a physical therapist. The research showed that the Brazilian profile is to prescribe physical therapy between the second and fourth postoperative weeks, continuing for four to eight weeks, with a satisfactory result in 98% of cases. which is aligned with existing studies on HV management. A consensus can be observed in the type of treatment prescribed in the postoperative period, where strengthening the foot core and scar tissue release are part of most postoperative physical therapy guidelines[13,15].

The strengths of this study include its innovative approach as the first investigation of Brazilian specialists' practices for HV and the participation of a substantial number of board-certified foot and ankle specialists. However, the study has limitations. These include the inability to ensure responses from all eligible specialists, the potential for response bias given the voluntary nature of participation, and the lack of stratification by case complexity or severity. Furthermore, as a cross-sectional study, it does not allow for longitudinal analysis or direct intervention comparisons, which limits the depth of causal inferences that can be drawn. Future studies addressing these limitations, such as incorporating case-specific data or comparative designs, could provide a more comprehensive understanding of treatment practices.

Conclusion

For those opting for conservative treatment, there is a consensus in Brazil regarding the change of footwear and lifestyle, aligning with the preference of experts worldwide.

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Appendix 1. Questionnaire

1 – How old are you?

2 – How many hallux valgus surgeries do you perform per year?
☐ Less than 10 ☐ 10 to 30 ☐ 30 to 50 ☐ Over 50

3 – Which surgical technique do you use the most?
☐ Chevron ☐ Scarf ☐ MICA and other percutaneous ☐ Lapidus ☐ Other

4 – Do you offer any type of non-surgical treatment for hallux valgus?
☐ Yes ☐ No

5 – If not, what motivates you not to recommend it? (select more than one option if necessary)
☐ Hallux valgus is a surgical condition
☐ Non-surgical treatments are ineffective
☐ Evidence for non-surgical treatment is weak
☐ I do not achieve good results with non-surgical treatment
☐ My patients do not want non-surgical treatment

6 – If yes, do you achieve good results?
☐ Yes ☐ No

7 – If yes, what motivates you to recommend it? (select more than one option if necessary)
☐ Patient's age ☐ Patient's request
☐ I do not operate without first trying a conservative treatment ☐ I believe non-surgical treatment can benefit some patients

8 – If yes, Se sim, por quanto tempo antes de indicar a cirurgia?
☐ Less than 30 days ☐ 30 to 90 days ☐ 90 to 180 days ☐ Over 180 days

9 – If yes, what do you recommend to your patient? (select more than one option if necessary)
☐ Changing the type of footwear
☐ Prefabricated orthosis
☐ Custom orthosis
☐ Night orthoses
☐ Insoles
☐ Silicone protectors
☐ Bandages
☐ Physical therapy
☐ Stretching
☐ Muscle strengthening
☐ Foot core strengthening
☐ Massage
☐ Changing lifestyle habits
☐ Oral medications
☐ Injectable medications
☐ Topical medications
☐ From this point, the questions will be asked after the surgical procedure.

10 – Do you prescribe physical therapy after the surgical procedure?
☐ Yes ☐ No

11 - If no, what motivates you not to recommend it? (select more than one option if necessary)
☐ I don't see the benefit of physical therapy after surgery
☐ My patients don't want to do physical therapy
☐ I am afraid the physical therapist might "lose" the results of the surgery

12 - If yes, what motivates you to recommend it? (elect more than one option if necessary)
☐ Patient's age ☐ Patient's request
☐ I always prescribe physical therapy after surgical procedures ☐ I have better results with the help of the physical therapist

13 - If yes, how long after the surgical procedure do you recommend physical therapy?
- Immediately
- After the first week
- After the second week
- After the third week
- After the fourth week
- After the fifth week
- After the sixth week

14 - If yes, for how long do you maintain physical therapy?
☐ Less than 4 weeks ☐ 4 to 8 weeks ☐ 8 to 12 weeks ☐ More than 12 weeks ☐ Until the physical therapist discharges the patient

15 - If yes, do you achieve good results?
☐ Yes ☐ No

16 - If yes, do you ask the physical therapist to focus on specific aspects? (select more than one option if necessary)
- Bandages
- Stretching
- Muscle strengthening
- Foot core strengthening
- Massage
- Lymphatic drainage
- Scar release techniques
- Laser therapy
- Ultrasound

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Original Article

Arthroscopy with lateral ankle ligament stabilization: benefit versus cost comparison

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Abstract

Objective: Compare the differences in cost, complications, new intra-articular diagnoses, and reoperations among patients with ankle instability submitted to lateral ankle ligament repair/reconstruction with or without arthroscopic procedures.

Methods: A retrospective analysis of 2,428 patients from the PearlDiver Humana dataset with ankle sprain or instability codes and compared outcomes between those submitted to lateral ankle ligament repair/reconstruction with or without arthroscopy.

Results: Patients without arthroscopy had higher complication rates (9.87% vs. 5.41%; χ^2[1, n = 1,236] = 5.83, p = 0.01), while the difference in reconstruction groups was insignificant (p = 0.09). Arthroscopy groups had higher rates of newly diagnosed intra-articular pathology: repair with arthroscopy (57.0%) vs. without (35.6%; χ^2[1, n = 1,236] = 44.47, p < 0.001); reconstruction with arthroscopy (63.0%) vs. without (39.8%; χ^2[1, n = 1,211] = 61.90, p < 0.001). Reoperation rates for intra-articular pathology were higher in the arthroscopy group (6.89% vs. 4.18%; χ^2[1, n = 2,433] = 8.09, p = 0.006), with significantly shorter time to reoperation (303 vs. 474 days, p = 0.045).

Conclusions: Arthroscopy does not increase complication rates and allows for earlier diagnosis and treatment of intra-articular pathology, potentially leading to earlier reoperation.

Level of evidence III; Retrospective Comparative Study.

Keywords: Lateral Ligament, Ankle; Arthroscopy; Ankle injuries; Cost-benefit analysis.

Introduction

Ankle sprains are a common injury, with an estimated incidence of 2.15 per 1,000 person-years presenting to an emergency department[1]. Although most cases can be treated non-operatively, a lateral ligament repair or reconstruction may be indicated in patients with chronic ankle instability following the initial injury[2]. Some patients suffer from persistent ankle pain despite the overall success of these procedures. The source of this pain is often thought to be unrecognized intra-articular pathology[3]. For this reason, ankle arthroscopy has been performed concomitantly with lateral ligament repair/reconstruction to identify and correct such pathology.

Intra-articular pathology has been found to accompany chronic ankle instability in 65%-90% of cases[4-6]. There is a clear indication for ankle arthroscopy when such pathology is identified by imaging or suspected clinically. Further, diagnostic arthroscopy immediately before lateral ligament repair/reconstruction has shown utility in identifying previously undiagnosed intra-articular pathology in at least two small case series[3,7]. For instance, in one study, magnetic resonance imaging detected only 72% of osteochondral

Study performed at the University of Kansas School of Medicine-Kansas City, Kansas City, KS, USA.

Correspondence: Sterre van den Anker. 10730 Nall Ave, Overland Park KS, 66211. **Email:** svandenanker@kumc.edu. **Conflict of Interest**: **Bryan Vopat reports these conflicts:** Artelon: Paid Consultant; AOFAS board/committee member; Altior, Carbon 22, and Spinal Simplicity: stock options. **Scott Mullen reports these conflicts:** Arthrex: Paid Consultant **Paul Schroeppel reports these conflicts:** Vericel: Paid Consultant **Source of funding:** None. **Date received:** October 29, 2024. **Date accepted:** November 24, 2024. **Online:** December 30, 2024.

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injuries subsequently identified by arthroscopic examination[7]. However, arthroscopy is an additional procedure that carries risks and could potentially increase the cost of lateral ligament repair/reconstruction. For example, there is a risk of injury to the superficial peroneal nerve in arthroscopy when creating the lateral portal[8,9].

To more clearly establish the utility of diagnostic ankle arthroscopy concomitant with lateral ligament repair/reconstruction, we sought to compile and evaluate a much larger case series than in published studies. The objective of this study is to compare the rates of diagnosis, reoperation, and complications for intra-articular pathology in lateral ligament surgeries with concomitant arthroscopy versus those without arthroscopy using a large health insurance database. In addition, analyze the costs associated with the procedures. We expect that the addition of diagnostic arthroscopy in lateral ligament surgeries will lead to earlier identification of intra-articular pathology and a lowered postoperative complication rate.

Methods

Data were collected from the PearlDiver Technologies Humana dataset, including records from over 25 million distinct patients at the time of the study from 2007 to the first quarter of 2017. A total of 2,428 patients with records of either ankle sprain or instability were included. These records indicated that patients were submitted to one of two procedures: lateral ankle ligament repair (native or *in situ* tissue) or lateral ankle ligament reconstruction (tendon autograft or allograft).

The study population was subdivided based on whether patients had at least one arthroscopic procedure (debridement or synovectomy) performed on the same day as the ligament repair or reconstruction. Patients in the "without arthroscopy" groups were confirmed to have no record of arthroscopic procedures on the day of the initial surgery, while patients in the "with arthroscopy" groups were submitted to concomitant ankle arthroscopy.

The two repair and two reconstruction groups were mutually exclusive, though 19 patients had records of repair and reconstruction procedures performed on separate occasions. These patients were included in the study, with each surgery considered separately. In total, 2,447 records were analyzed, excluding 408 patients with the current procedural terminology (CPT) codes for repair and reconstruction on the same day. Table 1 lists the International Classification of Diseases (ICD) 9/10 and CPT codes used for the inclusion and exclusion criteria.

The mean cost per patient, the incidence of complications, the rate of new intra-articular diagnoses, the proportion of patients requiring reoperations, and the mean time to reoperation were analyzed across all four groups. Costs, defined in the PearlDiver Humana dataset as reimbursements from Humana, were calculated by summing all patient records associated with ankle injury or instability ICD-9/10 codes within 90 days of the primary procedure. Complications were also evaluated within these 90 days and included hemorrhage, hematoma, wound disruption, peroneal nerve injury, painful hardware, infection, deep vein thrombosis, pulmonary embolism, and postoperative shock. Table 1 lists the ICD-9/10 codes used for these complications.

Reoperations were defined as any surgical procedures on the ankle occurring after the day of the primary procedure. These included ligament repair or reconstruction, arthroscopic debridement, synovectomy, arthrodesis, loose body removal, osteochondral defect excision, arthrotomy with joint exploration, incision and drainage, and syndesmosis repair. Intra-articular reoperations included all reoperations except liga-

Table 1. ICD-9/10 and CPT codes used for inclusion/exclusion criteria and complication assessment.

Inclusion/ Exclusion Criteria description	Code
Ankle Instability	ICD-10-D-M25371: ICD-10-D-M25373 ICD-9-D-71887
Ankle Sprain	ICD-10-D-S93401: ICD-10-D-S93409 ICD-10-D-S93411: ICD-10-D-S93419 ICD-10-D-S93491: ICD-10-D-S93499 ICD-9-D-84500: ICD-9-D-84509
Lateral Ankle Ligament Repair	CPT-27695
Lateral Ankle Ligament Reconstruction	CPT-27698
Ankle Arthroscopy	CPT-29897 CPT-29898 CPT-29895 CPT-29891 CPT-29894 CPT-29892
Complication Descriptions	**Code**
Postoperative shock	ICD-10-D-T8110X, ICD-10-D-T8111X, ICD-10-D-T8112X, ICD-10-D-T8119X
Hemorrhage	ICD-9-D-99800: ICD-9-D-99809, ICD-10-D-M96810, ICD-10-D-M96830, ICD-9-D-99811
Hematoma	ICD-10-D-M96840, ICD-9-D-99812
Disruption of wound	ICD-10-D-T8130X, ICD-10-D-T8131X, ICD-10-D-T8132X, ICD-9-D-99830: ICD-9-D-99833
Infection	ICD-10-D-T814XX, ICD-10-D-T8460X, ICD-10-D-T847XX, ICD-9-D-99851, ICD-9-D-99859, ICD-9-D-99667
Injury to peroneal nerve	ICD-10-D-S8410XA, ICD-9-D-9563
Painful hardware	ICD-10-D-T8484X, ICD-9-D-99678
Deep venous thrombosis	ICD-10-D-I82400: ICD-10-D-I82499 ICD-10-D-I824Y0: ICD-10-D-I824Y9 ICD-10-D-I82ZY0: ICD-10-D-I824Z9 ICD-9-D-45340: ICD-9-D-45342
Pulmonary embolism	ICD-10-D-I2699, ICD-9-D41511, ICD-9-D-41519

ment repair/reconstruction and incision and drainage. Newly diagnosed intra-articular pathology was defined as ankle defects not previously recorded in a patient's history but first appearing on the day of surgery or thereafter (up to a maximum of 10 years post-operation). Assessed intra-articular pathology included synovitis/tenosynovitis, osteophytes, loose bodies, osteochondral defects, syndesmosis injury, other osteochondropathies, articular cartilage disorders, and osteoarthrosis. Due to the compliance of the Health Insurance Portability and Accountability Act, data on groups with fewer than 11 patients could not be reported.

The statistical significance of cost differences was determined using t-tests through PearlDiver's interface with the R statistical package. Differences in proportions were compared using Chi-squared tests, and differences in the mean time to reoperation were analyzed with t-tests using Open-Source Epidemiologic Statistics for Public Health (OpenEpi) version 3.01. P-values less than 0.05 were considered statistically significant.

Results

As shown in Table 2, the study compared four main groups: repair with arthroscopy (n = 314), repair without arthroscopy (n = 922), reconstruction with arthroscopy (n = 473), and reconstruction without arthroscopy (n = 738). Additionally, combined arthroscopy (n = 787) and non-arthroscopy (n = 1,660) groups were analyzed. The most common new diagnoses were tenosynovitis, sprain of the tibiofibular ligament, osteophytes, and loose bodies. A significantly higher proportion of patients in the arthroscopy groups had newly diagnosed intra-articular pathology compared to their respective non-arthroscopy groups. Among those diagnosed with intra-articular pathology, patients submitted to arthroscopy were significantly more likely to receive a diagnosis on the day of surgery rather than later (Table 3).

The most common reoperations involved repeat ligament repair/reconstruction and debridement. There was no significant difference in the proportion of patients submitted to reoperation between the arthroscopy and non-arthroscopy groups: repair with arthroscopy (9.6%) vs. without (8.1%; χ^2 [1, n = 1,236] = 0.6, p = 0.44) and reconstruction with arthroscopy (6.8%) vs. without (8.8%; χ^2 [1, n = 1,211] = 1.6, p = 0.20). Similarly, there was no significant difference in time to reoperation. However, there was a significant difference in the proportion of patients submitted to intra-articular reoperations between the combined arthroscopy and non-arthroscopy groups, with the mean time to reoperation being significantly shorter in the combined arthroscopy group (Table 4).

The most common complications included painful hardware, infection, deep venous thrombosis, and wound disruption. Patients in the repair without arthroscopy group had a significantly higher rate of complications than those in the repair with arthroscopy group. A similar trend was observed in the reconstruction groups, though it did not reach statistical significance (p = 0.045). However, when comparing the combined arthroscopy and non-arthroscopy groups, the non-arthroscopy group had a significantly higher rate of complications (Table 5).

Table 2. Study cohorts.

Group	With arthroscopy (Frequency)	Without arthroscopy (Frequency)	Total (Frequency)
Lateral ankle ligament repair	314	922	1,236
Lateral ankle ligament reconstruction	473	738	1,211
Combined (repair + reconstruction)	787	1,660	2,447

Table 3. Patients with new intra-articular pathology.

Lateral ankle ligament repair	With arthroscopy n = 314	Without arthroscopy n = 922	χ2	p-value
Total	179 (57.0%)	328 (35.6%)	44.3	< 0.001
Received Day of Surgery	163 (91.1%)	235 (71.6%)	26.4	< 0.001
Lateral ankle ligament reconstruction	**With arthroscopy n = 473**	**Without arthroscopy n = 738**	**χ2**	**p-value**
Total	300 (63.4%)	294 (39.8%)	62.0	< 0.001
Received day of surgery	259 (86.3%)	198 (67.3%)	29.8	< 0.001

Table 4. Reoperations for combined lateral ankle ligament repair and reconstruction with and without arthroscopy.

Combined reoperation type	With arthroscopy n = 787	Without arthroscopy n = 1,660	χ2	p-value
Any reoperation	62 (7.9%)	138 (8.3%)	0.1	0.74
Intra-Articular reoperation	54 (6.9%)	69 (4.2%)	8.1	0.004
Mean time to intra-articular reoperation (days)	303	474	-	0.045

Table 5. Complication rates of lateral ankle ligament repair and reconstruction with and without arthroscopy.

Intervention	With arthroscopy	Without arthroscopy	χ2	p-value
Repair	5.4% (17/314)	9.9% (91/922)	5.9	0.015
Reconstruction	5.1% (24/473)	7.6% (56/738)	2.9	0.088
Combined (repair + reconstruction	5.2% (41/787)	8.9% (147/1660)	10.3	< 0.001

The mean cost per patient was significantly higher in the repair group with arthroscopy ($5,991.32) compared to the repair group without arthroscopy ($3,677.11; $p < 0.001$). This trend also was observed in the reconstruction groups, with the cost of reconstruction with arthroscopy at $5,744.83 and without arthroscopy at $4,601.13 ($p < 0.001$). The cost difference between repair with arthroscopy and reconstruction with arthroscopy was not significant ($p = 0.59$), but the difference between repair without arthroscopy and reconstruction without arthroscopy was statistically significant ($p < 0.001$).

Discussion

Our findings demonstrate that ankle arthroscopy at the time of lateral ligament repair/reconstruction was more expensive but allowed for an increase in the identification of intra-articular pathology at the time of the chosen procedure. Although overall reoperation rates were similar, patients submitted to ankle arthroscopy were more likely to have reoperations for intra-articular pathology. These reoperations occurred significantly sooner (171 days) than for patients not undergoing arthroscopy. Ankle arthroscopy detects potentially pain-generating pathology that could be addressed either during the chosen procedure or later, potentially explaining the increased and earlier reoperations to address these issues.

Several studies have demonstrated the high prevalence of intra-articular pathology accompanying lateral ligament injuries in patients suffering ankle sprain or instability[3,4,5,10,11]. One case series showed that arthroscopy with lateral ankle ligament surgery identified many intra-articular pathologies, which were undiagnosed before surgery, most notably synovitis, cartilage injuries, and loose bodies[3]. The authors speculated that these defects would not have been detected without arthroscopy. However, there was no control group for comparison and follow-up time was limited to the surgery.

Our study is the largest reported case series of patients with chronic ankle instability submitted to repair or reconstruction having concomitant ankle arthroscopy. We found that, without arthroscopy, potential intra-articular pathology is more likely to be diagnosed later during the follow-up, which extended to a maximum of ten years after the initial ligament repair/reconstruction surgery. Due to the restrictions on reporting data for groups of patients fewer than 11 in the PearlDiver dataset, the rates of specific diagnoses from the arthroscopy were not available for comparison. Since some intra-articular pathology has been shown to affect patient outcomes more than others[12], future studies of a larger population may show more detailed reporting of arthroscopic findings.

Our study also corroborated the finding of Yasui et al.[9] that there was no reduction in the overall reoperation rate when lateral ligament repair surgeries were performed with concomitant arthroscopic procedures. However, in the current study, there was an increase in intra-articular pathology reoperations and a decreased reoperation time. This was likely due to intra-articular pathology, which was recognized arthroscopically and addressed sooner than in patients who did not have arthroscopy. Komenda and Ferkel showed in a study of 55 patients undergoing ligament repair with arthroscopy that 93% of patients had intra-articular injuries requiring intervention[13]. With the high prevalence of intra-articular injuries associated with chronic lateral ankle instability, early identification and treatment likely lead to earlier resolution of symptoms and better patient outcomes.

A recent systematic review found the most common complications of lateral ligament repair/reconstruction surgeries included wound issues, superficial nerve damage with sensory disturbances, and superficial infections[8]. The review also noted a wide range of complication rates among the cohorts studied[8]. Our study found no significant difference in the overall complication rate between lateral ligament reconstruction with or without arthroscopy. However, our data demonstrated a significantly lower proportion of patients with complications in the combined arthroscopy group than in the combined without arthroscopy group. This finding likely indicates other factors affecting complication rates independent of the use of concomitant arthroscopy.

As expected, the mean cost of the procedure was higher in the arthroscopy groups than in the non-arthroscopy groups. The higher cost in the arthroscopy groups reflects the cost of utilizing the arthroscopy equipment, and the additional operating room and anesthesia time. However, the added cost of arthroscopy may be offset by the opportunity to address arthroscopic findings sooner, allowing patients to return quicker to a functional state.

Our study has several limitations. As a retrospective database review, many variables remain uncontrolled. Data on small groups of less than 11 patients could not be reported due to the compliance of the Health Insurance Portability and Accountability Act, which limits detailed analysis of individual complications, diagnosis, and reoperation rates. The timing and accuracy of diagnoses and procedures rely on the providers' reporting practices, and some diagnoses may be clinically insignificant but still recorded. Additionally, minor complications captured in other studies may not be reflected here, as they may lack formal diagnostic codes reported to private insurers. The cost analysis was limited to reimbursements from private insurers, which may not accurately reflect patient costs or physician reimbursements.

Furthermore, the authors did not include outcome data in the study as they were not documented in the PearlDiver Humana Dataset, making it unclear whether the diagnosis and treatment of intra-articular pathology improved patient function. Determining the overall difference between the arthroscopy and non-arthroscopy groups is challenging without these outcome metrics. However, the need for reoperation could suggest that patients were not progressing as expected postoperatively, and early identification of intra-articular pathology in the arthroscopy group may have facilitated earlier reoperation and recovery.

Conclusions

Concomitant arthroscopy with lateral ankle ligament surgery is more expensive but does not appear to increase the overall complication rate. This approach enables surgeons to diagnose and treat more intra-articular pathologies, allowing defects to be addressed, on average, five months earlier with reoperation, which may justify the additional cost. Our findings support the hypothesis that concomitant arthroscopy leads to earlier identification of intra-articular pathology, potentially improving patient outcomes. Ankle arthroscopy seems to be a safe adjunct to lateral ankle ligament surgery for ankle sprain or instability, providing the opportunity to identify and treat intra-articular pathology that could potentially impact patient outcomes.

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Case Report

Leiomyoma of Achilles tendon sheath with sural neuropathy: a rare cause of lateral foot pain

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Abstract

Leiomyomas are well-known benign tumors of uterine smooth muscles. However, leiomyomas are rarely reported in the extremities, particularly in the foot and ankle. We present a case of a 52-year-old woman who presented to our outpatient clinic with complaints of nodular swelling in the posterior aspect of her left ankle with pain and tingling numbness in the lateral aspect of her foot. The excisional biopsy of the mass revealed leiomyoma, a smooth muscle origin tumor.

Level of evidence IV; Therapeutic study; Case report.

Keywords: Tumor; Leiomyoma; Sural nerve.

Introduction

Foot pain is known to significantly impact quality of life. It affects one in five individuals, with its incidence increasing with age, female sex, and obesity. Lateral foot pain can stem from various underlying causes, each requiring careful consideration for accurate diagnosis and effective treatment. Out of the long list of causes of lateral foot pain, common ones may include lateral ankle sprains, peroneal tendinitis, stress fracture, cuboid syndrome, or tarsal coalition(1). Neuropathic pain associated with tingling, numbness, and paresthesia in the lateral aspect of the foot may originate from spinal causes with nerve root compression, diabetic neuropathy, or local causes like entrapment of the nerve or pressure on the nerve.

Leiomyomas are one of the most encountered smooth muscle tumors, mainly originating in the uterine smooth muscles. However, they can be seen in the smooth muscles present anywhere in the body, like the esophagus or intestinal smooth muscles(2). Although rare and benign, Leiomyomas involving the foot and ankle can grow and cause pressure on adjacent structures, causing various symptoms.

We present a case involving a female patient with leiomyoma of Achilles tendon sheath with compression of the sural nerve, resulting in neuropathic symptoms in the lateral aspect of the foot.

Case description

A 54-year-old female presented to our outpatient clinic with a peanut-sized swelling in the posterior aspect of the left ankle for eight months (Figure 1). She also complained of pain and tingling sensations in the lateral aspect of the foot and ankle. A thorough clinical examination revealed a 1 x 1 cm mass over the posterolateral aspect of the ankle, approximately 4 cm proximal and posterior to the lateral malleolus, which was firm, non-compressible, and moderately tender. It was fixed to underlying structures, and skin over the mass appeared normal. Sensations over the lateral aspect of the midfoot and hindfoot were decreased compared to the opposite side. Unilateral involvement of the foot with no history of any chronic illness ruled out any systemic cause of neuropathy.

A lateral radiograph of the ankle showed a soft tissue shadow and confirmed its no connection with the underlying bone. Ultrasonography showed a hypoechoic shadow in the area adjacent to the tibialis anterior tendon (Figure 2).

With the sural nerve neuropathic symptoms, clinical suspicion of peripheral nerve sheath tumors like schwannoma was raised, and the patient was planned for an excisional biopsy of the tumor. A 2–3 cm incision was performed centering over the mass on the posterolateral aspect of the

Study performed at the Kalinga Institute of Medical Sciences, Bhubaneswar, Odisha, India.

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ankle. Intraoperatively, the tumor was found to be originating from the Achilles tendon sheath, and it was compressing the adjacent sural nerve and saphenous vein (Figure 3). The greyish-white mass was excised in toto and sent for histopathology (Figure 4). The sural nerve was examined for any lesion due to the pressure, and the wound was closed in layers.

Histopathological examination showed spindle cells with no mitotic figures or necrosis suggestive of leiomyoma. Immunohistochemistry showed diffuse positivity for vimentin (Figure 5).

Due to such an unusual and rare location of leiomyoma, suspicion of multiple cutaneous and uterine leiomyomatosis (MCUL) or Reed's syndrome was raised. The patient had a gynecological consultation to rule out the same.

Follow-up at two weeks showed good wound healing and improvement in the neuropathic foot pain. Subsequent follow-ups at three and six months did not show any sign of recurrence of the tumor.

Discussion

Soft tissue tumors occurring in the foot and ankle may include a variety of benign and malignant lesions that originate from adipose tissue, fibrous tissue of tendon sheaths, skeletal or smooth muscles, vascular tissues, or primitive mesenchyme or hamartomatous tissue[3].

Leiomyomas are benign smooth muscle tumors most commonly found in the uterine smooth muscles. Although

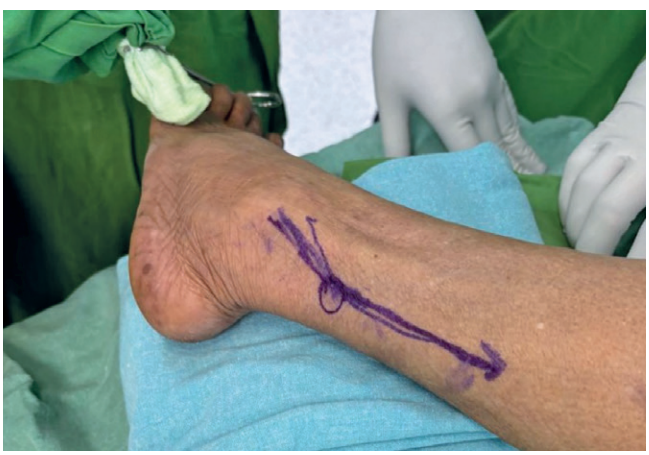

Figure 1. Peanut-shaped swelling over the posterior aspect of the fibula.

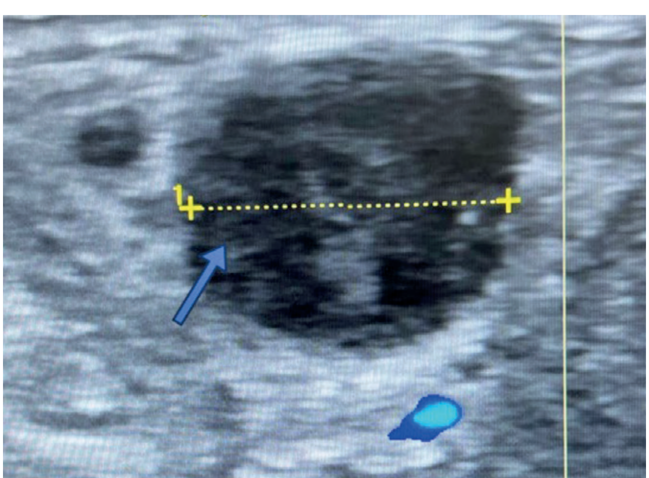

Figure 2. Ultrasonography showing hypoechoic shadow adjacent to the tibialis anterior tendon.

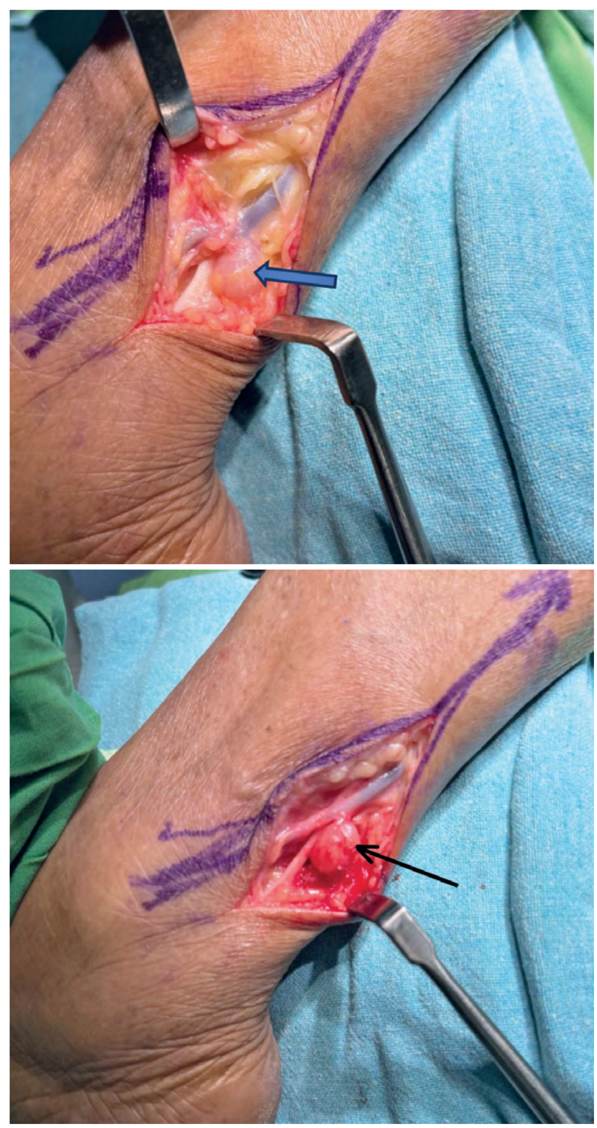

Figure 3. Tumor originating from the Achilles tendon sheath compressing on the sural nerve.

such tumors are reported in the gastrointestinal system, their occurrence in lower extremities is quite rare.

Cutaneous leiomyomas are 3%–5% of all leiomyomas. Depending on the origin of the cell type, they can be 1) Pilar leiomyoma—from arrector pili muscles, 2) Angioleiomyoma—from smooth muscle cells of tunica media of blood vessels, and 3) Genital leiomyoma—from smooth muscles of scrotum and labium[4].

The usual onset age of pilar leiomyoma is adolescence or early adult life, with more female sex preponderance[5]. They usually present as nodular tender masses, though the cause of pain is not clear and is believed to result from contraction of underlying smooth muscle or due to pressure on adjacent structures. Aggravating pain factors can be touch, exposure to cold, or emotional disturbance.

Angioleiomyoma originates from smooth muscles of tunica media of blood vessels and can be solid, venous, or cavernous. The solid form usually occurs in females in their 4th to 6th decade of life and is more commonly found in the lower extremities. Cavernous forms have more male preponderance and higher incidence in the head, neck, and upper extremities. Angioleiomyomas usually present with small solitary lesions with pain or tenderness with occasional exacerbation of pain during menses and pregnancy.

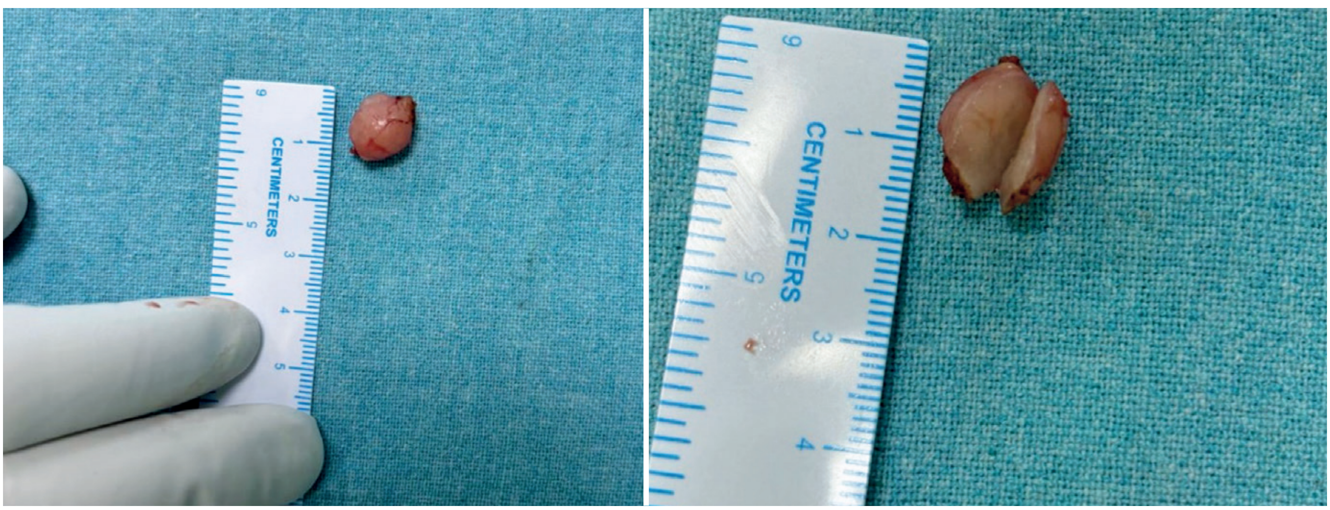

Figure 4. Greyish-white mass excised.

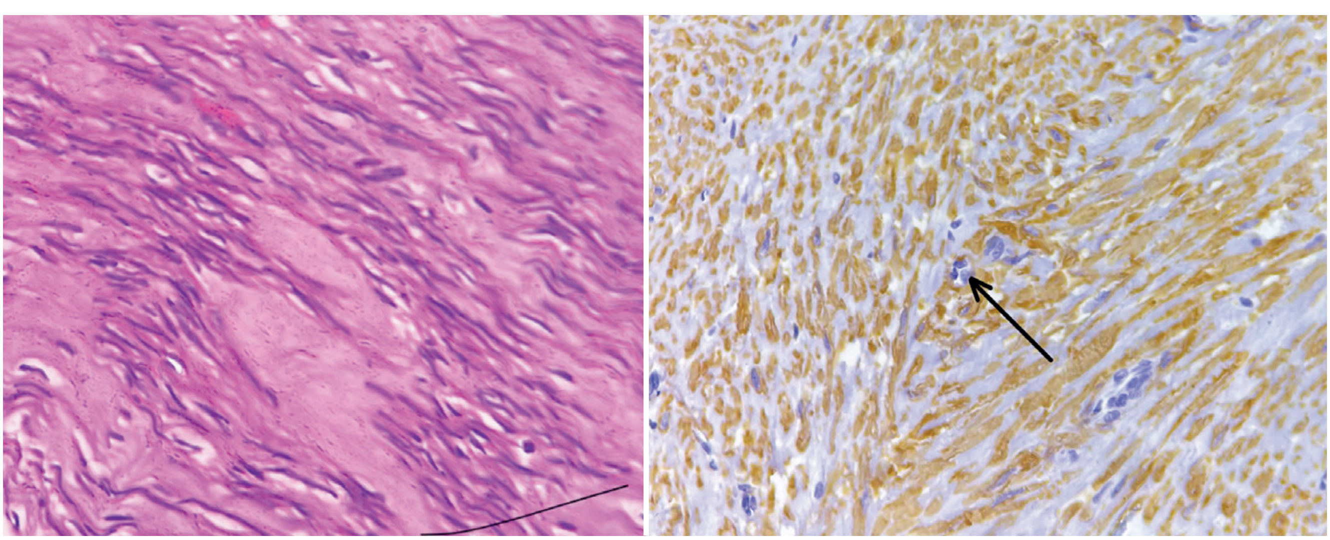

Figure 5. Histopathological examination shows spindle-shaped cells arranged in a fascicular pattern. Immunohistochemistry shows vimentin positivity.

Cutaneous leiomyomas, particularly when in multiple, should raise the suspicion of MCUL or hereditary leiomyomatosis and renal cell cancer (HLRCC) or Reed's syndrome[(6)].

Patients should be carefully evaluated for any other site of symptomatic or asymptomatic leiomyoma, and thorough family history should be considered to eliminate any form of malignancy. Any clinical suspicion of HLRCC should be followed by genetic testing if diagnostic criteria for HLRCC are met[(7)]. We should not neglect asymptomatic angioleiomyomas as the consequence of delay or mistreatment increases morbidity and the potential risk of malignant transformation[(8)].

In our case, we found a leiomyoma that originated from the Achilles tendon sheath, which is quite an unusual location for the tumor. A solitary tender nodule with neuropathic pain on the lateral aspect of the foot raised high suspicion for peripheral nerve sheath tumors like schwannoma. However, the intraoperative findings of sural nerve compression by adjacent tumors from the tibialis anterior sheath correlated with our clinical findings.

Local recurrence or malignant change is extremely rare after excision. Only marginal excision usually suffices for the treatment of cutaneous leiomyoma.

Despite the low incidence of leiomyoma in the foot and ankle, it must be considered as one of the differential diagnoses in patients presenting with resistant foot pain that can not be attributed to any other mechanical or neurological causes. A careful evaluation with ultrasonography or magnetic resonance imaging can reveal even small tumors and appropriate excisions can be planned. Surgical excision of the tumor is often curative, with recurrence or malignancy being extremely rare.

Authors' contributions: Each author contributed individually and significantly to the development of this article: TKM *(https://orcid.org/0000-0002-5167-5273) Statistical analysis, clinical examination, data collection; KS *(https://orcid.org/0009-0002-9025-4655) Performed surgeries, formatting of the article; SP *(https://orcid.org/0009-0003-1826-6982) Conceived and planned the activities that led to the study, PR *(https://orcid.org/0000-0001-9717-7088) Participated in review process. All authors read and approved the final manuscript. *ORCID (Open Researcher and Contributor ID) iD.

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Case Report

Acute compartment syndrome with dorsalis pedis artery rupture after an acute ankle inversion trauma

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Abstract

Acute compartment syndrome in lower limbs is commonly seen in fractures, crash injuries, vascular impairment, and rarely due to ankle sprain. We report a case of a 16-year-old male who was admitted to the emergency room after a traumatic lateral ankle inversion. Significant swelling and moderate pain were present at admission. Plain radiographs showed no bone abnormality. After 60 minutes, the classic signs and symptoms of acute compartment syndrome began, with no response to painkillers. Doppler ultrasound revealed arteries occlusion distal to the superior portion of the extensors retinaculum of the ankle. Anterior foot and ankle fasciotomy were performed, with an angiography revealing a dorsalis pedis artery rupture; both ends were ligated intraoperatively. Postoperative flow was observed through the local collateral system.

Level of Evidence IV; Therapeutic Studies; Case Report.

Keywords: Compartment syndrome; Pediatric; Ankle injuries; Supination.

Introduction

Ankle sprain resulting from an inversion mechanism is a common injury in daily practice[1]. These injuries rarely lead to acute compartment syndrome (ACS)[1,2,3]. ACS is an increase in interstitial pressures within a closed compartment resulting from high-energy mechanisms like fractures and crash injuries, leading to alterations in local circulation that can cause necrosis of the affected tissues[4]. Clinically, pain is non-proportional with the observed injury, does not respond to analgesics, and occurs with passive and active muscle stretching. Other clinical signs include paresis, paresthesia, diminished pulses, and changes in skin color[4]. Timely interventions are key to avoiding irreversible damage. This case report describes an ACS of the foot and ankle due to a dorsalis pedis artery rupture after an ankle inversion.

Case description

A 16-year-old male was admitted to the emergency room after suffering an ankle inversion of the left ankle while playing basketball. This case report was approved by the Institutional Review Board.

He was treated promptly, a routine protocol of oral painkillers was administered, and radiographs were performed. Thirty minutes after admission, the patient reported increasing pain in the anterior and lateral part of the left ankle, rated 10/10 on the visual analog pain scores (VAS). Passive flexion of the toes increased pain, paresis, and "cramps" in the leg were reported by the patient. Intravenous opioids were administered, and after 15 minutes, pain decreased from 10/10 to 6/10 on VAS; however, at a passive extension of the toes maneuver, the pain increased to 10/10 on VAS. Plain radiographs demonstrated no signs of fracture; however, a considerable amount of swelling in the lateral aspect of the ankle was observed (Figure 1).

A physical exam revealed significant swelling of the lateral aspect of the ankle and "ring-like" structures, corresponding to the anatomic borders of the superior extensors retinaculum (Figure 2). No pulses were palpable distal to the dorsal retinaculum, except for a diminished posterior tibialis artery

Study performed at the Hospital Zambrano Hellion TecSalud, San Pedro Garza Garcia, Nuevo León, Mexico.

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pulse. A Doppler ultrasound was performed, and no pulses distal to the superior extensor retinaculum were observed, except for biphasic posterior tibialis (Figure 3).

The patient was taken emergently to the operating room 90 minutes after the onset of these symptoms. Epidural anesthesia was administered. The superior extensor retinaculum was liberated using a dorsal fasciotomy, and a 50cc hematoma under the retinaculum was found and drained (Figure 4). The skin discoloration partially improved; however, the dorsalis pedis artery rupture was found. The rupture was confirmed by angiography (Figure 5), but due to the avulsed and damaged vessel, repair was not possible, and ligation was performed instead. Intraoperatively, collateral connections of the dorsalis pedis artery were confirmed by angiography. Other intraoperative findings included completely ruptured anterior and posterior tibiofibular ligaments and the calcaneofibular ligament.

Postoperatively, pain improved. The patient reported no pain from passive toe stretching, and a 6-hour postoperative Doppler ultrasound confirmed triphasic flows on the posterior tibialis. The patient was discharged three days after the surgery.

Figure 1. Anterolateral and lateral views of non-weight-bearing ankle radiographs.
There are no signs of fracture but a significant increase in soft tissue volume in the anterolateral region of the ankle, marked by a star in the anterolateral view and an asterisk on the lateral view.

Discussion

The most important finding of this report is that an ankle inversion may rarely produce a traumatic dorsalis pedis artery rupture, even in pediatric patients. This injury causes an expanding hematoma that may induce an ACS. The ACS requires prompt diagnosis and treatment with fasciotomy, hematoma evacuation, and artery repair or ligation.

ACS after traumatic injuries in the lower extremity, particularly ankle sprains, have been described due to vascular disruptions, aneurysms, or muscle belly disruption of the peroneus longus[3,5,6]. When the perforating branch of the peroneal artery is affected, it causes an ACS of the lower leg and ankle[3,5]. When the patient presents with a muscle disruption of the peroneus longus, the ACS most commonly occurs in the lateral compartment of the leg[6]. Our patient presented with ACS of the anterior compartment of the foot and ankle due to a dorsalis pedis artery rupture.

Figure 2. Clinical image of the ankle.
Image showing the "ring-like" structures marked with arrows corresponding to the anatomic borders of the superior extensor retinaculum.

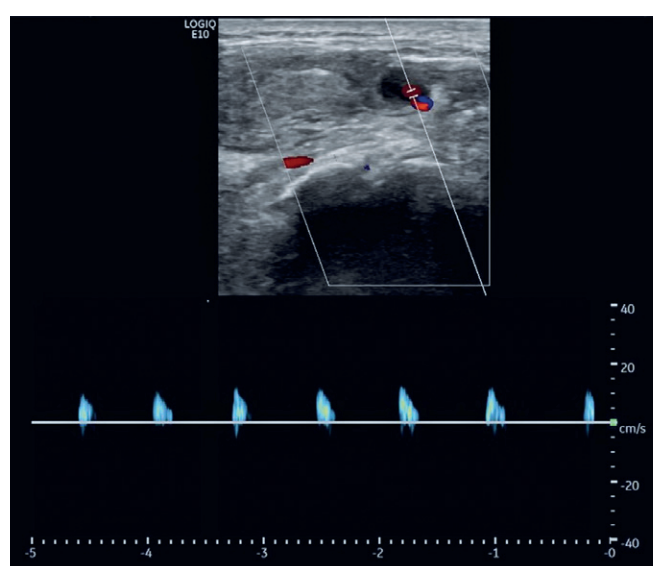

Figure 3. Doppler ultrasound showing the obliteration of the blood flow at the level of the superior extensor retinaculum.

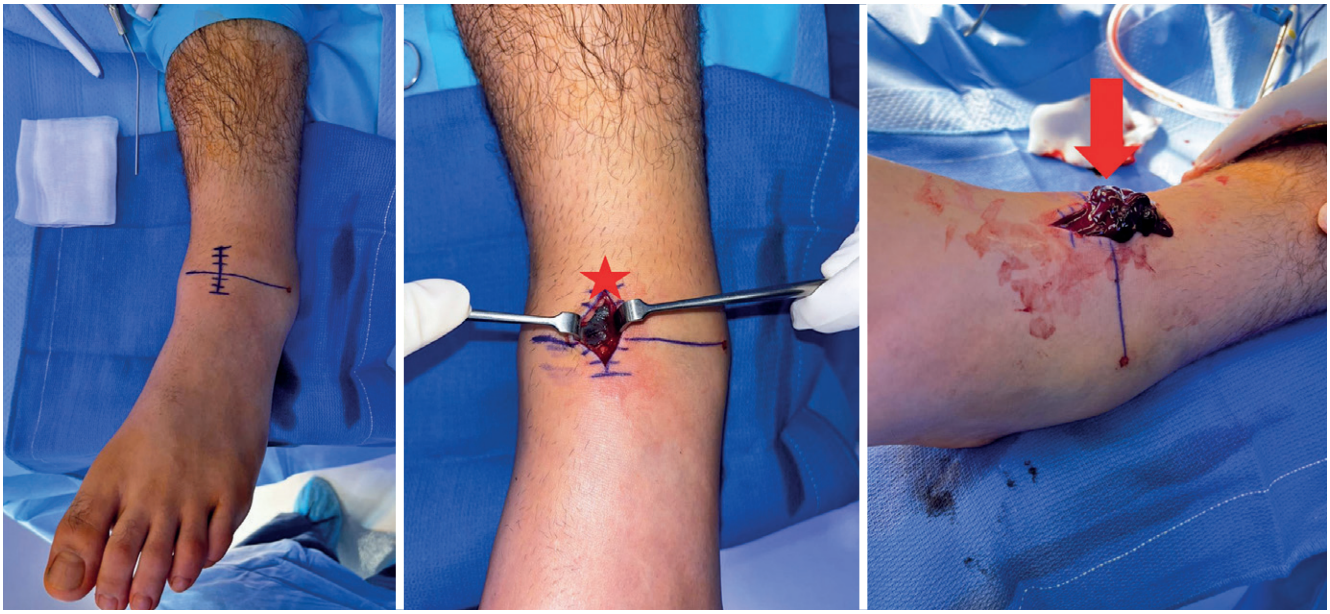

Figure 4. Surgery landmark, incision, and exposure. The first image on the left shows the surgery landmarks in the superior extensor retinaculum. The central image marked with a star shows the superior extensor retinaculum. The image on the right with the arrowhead shows the hematoma drained after the liberation of the superior extensor retinaculum.

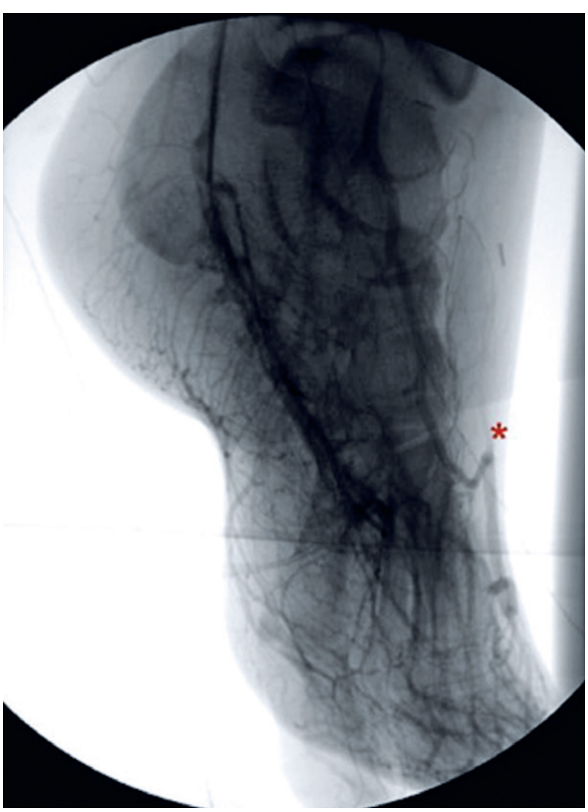

Figure 5. Angiography of the foot. Intraoperative angiography, where the asterisk marks the dorsalis pedis artery rupture.

Maguire et al.[5] in 1972 reported the first case of an ACS after an ankle inversion on a 19-year-old basketball player. The patient suffered a traumatic aneurysm in the perforating branch of the peroneal artery[5]. Later, Ward et al.[3] described a rupture of the perforating branch of the peroneal artery after an ankle inversion for the first time. They presented a case of a 23-year-old soldier injured while playing basketball[3]. Similarly, Kemp et al.[7] described a 24-year-old adult male with a similar injury after an ankle inversion[7]. The most common artery that causes ACS after ankle inversions is the perforating branch of the peroneal artery. Maguire et al.[5] theorized about this, describing the artery's trajectory through the interosseous membrane as the cause of its susceptibility to stress in ankle flexion and inversion. These injuries may cause either a partial or complete disruption or a false aneurysm of the artery. Also, 3.5% of the population has a vascular anomaly of this artery, resulting in the alteration course of the artery being more likely to be injured[5].

According to the literature, ACS after ankle inversion in the pediatric population is even more uncommon than in adults. Hull et al.[6] reported a case series of three pediatric patients who suffered an ACS after ankle inversion. The diagnosis was an avulsion of the muscle belly of the peroneus longus, and surgical treatment included fasciotomy and debridement or tenodesis of the peroneus longus to the brevis. All return to sports between 3–4 months[6]. Another report by Livingston et al.[8] described 39 cases, including six females with ACS; however, the report is brief, and they seem to include adults in their study[8]. On the other hand, Raad et al.[2] reported an ACS on a 10-year-old female patient who suffered an ankle inversion after jumping out of a trampoline and was diagnosed with a rupture of the perforating branch of the peroneal artery and treated surgically[2]. To our knowledge, this is the fourth case reported of ACS after ankle inversion while playing basketball[3,5,9].

Foot and ankle ACS are rare, often undiagnosed, and represent less than 5% of the ACS in the body[10]. However, to our knowledge, this is the first case that combines inversion in basketball and a dorsalis pedis artery rupture in a pediatric patient.

Authors' contribution: Each author contributed individually and significantly to the development of this article: GAVV *(https://orcid.org/0000-0001-9712-8227) Wrote the paper and participated in the reviewing process; OIVG *(https://orcid.org/0000-0002-7958-9676), and GLB *(https://orcid.org/0000-0002-9074-8973) Performed the surgery and data gathering; JFGS *(https://orcid.org/000-0001-6465-2372) Conceived and planned the activities of each author that led to the writing of the study; AHL *(https://orcid.org/0000-0001-5409-176X) Wrote the paper and participated in the reviewing process. All authors read and approved the final manuscript.*ORCID (Open Researcher and Contributor ID iD.

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Case Report

Chronic exertional compartment syndrome of the deep posterior compartment the leg: a rare presentation*

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Abstract

The chronic exertional compartment syndrome predominantly affects young athletes and often requires surgery when conservative treatments fail. The anterior compartment is the most commonly involved, accounting for 72.8% of cases, while isolated involvement of the deep posterior compartment is rare, occurring in only 2.8% of cases. This study presents a case of isolated deep posterior compartment syndrome and demonstrates a minimally invasive decompression technique for faster rehabilitation and early return to activity. A 26-year-old male athlete presented with posterior leg pain after running, unresponsive to conservative treatment. Stress magnetic resonance imaging revealed isolated deep posterior compartment involvement. Patient underwent minimally invasive segmental fasciotomy of the leg's four compartments, with excellent postoperative recovery and no deficits. Surgical intervention remains the gold standard for maintaining activity levels in athletes, and a high index of suspicion is crucial for diagnosis and treatment of this rare pathology.

Level of evidence IV; Therapeutic study; Case report.

Keywords: Chronic exertional compartment syndrome; Minimally invasive surgical procedures; Athletes; Sports Medicine; Sports.

Introduction

Chronic exertional compartment syndrome (CECS) of the leg is a pathology that affects mostly young athletes, affecting their performance and also leading to a reduction in activity level and/or exercise abstention[1-3]. This condition might be found in any compartment of the leg, but is more commonly anterolateral, followed by the isolated impairment of the anterior and lateral compartments[1,4-6]. Isolated impairment of the deep posterior compartment is a very rare condition, occurring in only 2.8% of patients[5]. Diagnosis must be suspected in patients complaining of pain initiated during exertion, being confirmed by compartment pressure measurement or imaging methods[2,6,7]. Open surgical decompressive fasciotomy is the gold-standard treatment, but recent studies have shown promising results with minimally invasive and endoscopic techniques[2,4,8,9]. In this article, we report a rare case of bilateral, isolated deep posterior compartment CECS treated with a minimally invasive surgical approach after failed conservative measures.

Case description

A 26-year-old man presented with bilateral leg pain for 18 months, initiated after at least five minutes of exertion. He worked as a military police officer and used to practice running and swimming. Symptoms were limiting his job and exercise performance. Patient-reported pain was up

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

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to nine on the visual analog scale, involving the posterior region of the leg, especially while running. He had already tried conservative measures, such as reducing training levels, using nonsteroidal anti-inflammatory drugs, and more than 100 sessions of physical therapy with stretching exercises, massage, and transcutaneous electrical nerve stimulation. Physical examination revealed mild pain on palpation of the posterior muscle bellies and diffuse mild pain on palpation of the anterior tibia. He also had a small fascial hernia in the lateral compartment, palpable bilaterally. No reduction of strength or numbness was remarkable, and the other examination points were unremarkable. Post-effort magnetic resonance imaging (MRI) was requested, showing bilateral volumetric enhancement of the deep posterior compartments when compared to pre-exertional sequences. It also described a 20% enhancement of the signal of the muscle bellies of the flexor digitorum longus and flexor hallucis longus, configuring CECS (Figure 1). A minimally invasive surgical approach was proposed to allow fasciotomy of the compartment. Patient was taken to the operating room and both lower limbs were prepared with standard drapes. Tourniquet was not used for this approach to allow bleeding control and avoid post-operative hematoma. We performed a single 4 cm medial incision to release the fascia of the superficial and deep posterior compartments and two 4 cm lateral incisions that allowed fasciotomy of anterior and lateral compartments (Figures 2 and 3). The fascia was incised with a curved Metzenbaum scissor. Complete release of all four compartments was achieved and checked by palpation. Limbs were protected with standard dressing and weight-bearing was immediately allowed as tolerated. At the first postoperative visit, after one week, patient was able to walk with no need of crutches and had normal strength in all muscular groups of both legs, with no complaint of paresthesia (Figure 4). After six weeks, he returned to strengthening activities at the gym and was able to run without pain after nine weeks.

Discussion

The CECS is a condition that causes pain during exercise, especially in young runners. A high clinical suspicion is required when facing a patient with chronic exertional leg pain, because most patients are asymptomatic during rest. Ruling out differential diagnosis is an important step in patients' care. Pathologies such as stress fractures and medial tibial stress syndrome are frequently associated with this clinical picture, and MRI is a valuable tool for excluding these confounding hypotheses[4].

Isolated impairment of the posterior compartments is extremely rare[5]. In a retrospective review, Davis et al. found that isolated involvement of the deep posterior compartment occurred in only 2.8% of patients[5]. The involvement of this compartment was more frequent in association with other compartments, totaling 18.9% of cases. The anterior compartment was involved in 42.5% of patients and the lateral compartment, in 35.5% of patients. Among these patients, 63.4% had bilateral positive tests.

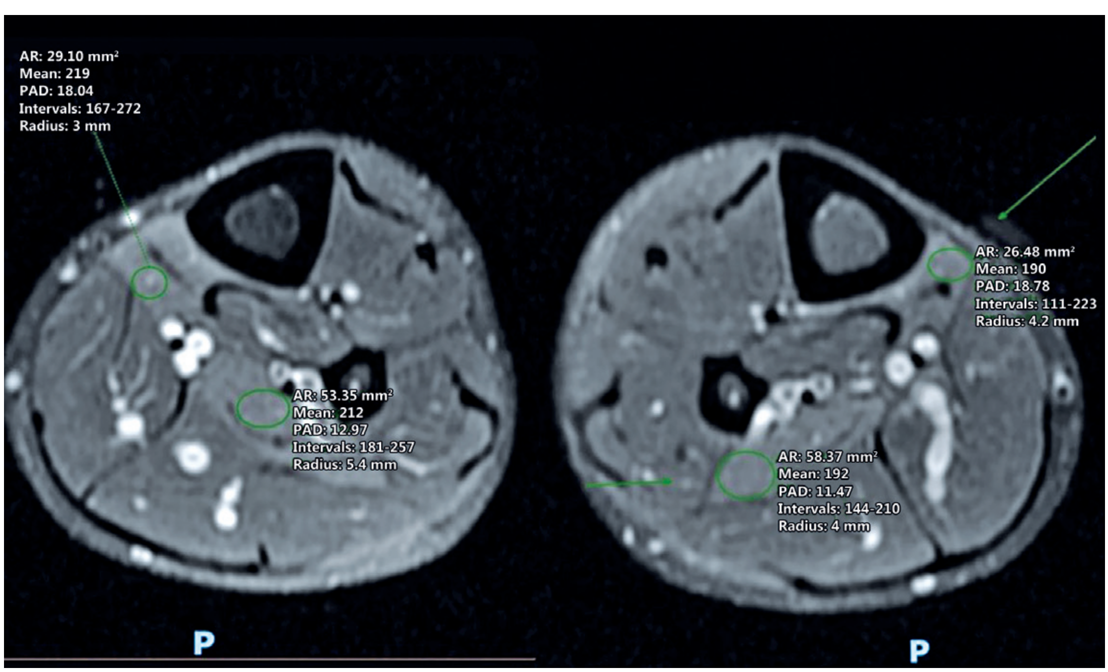

Figure 1. Patient T2-weighted, post-effort MRI image showing increased volume and signal.

Figure 2. Distal lateral incision showing the released fascia of the lateral compartment.

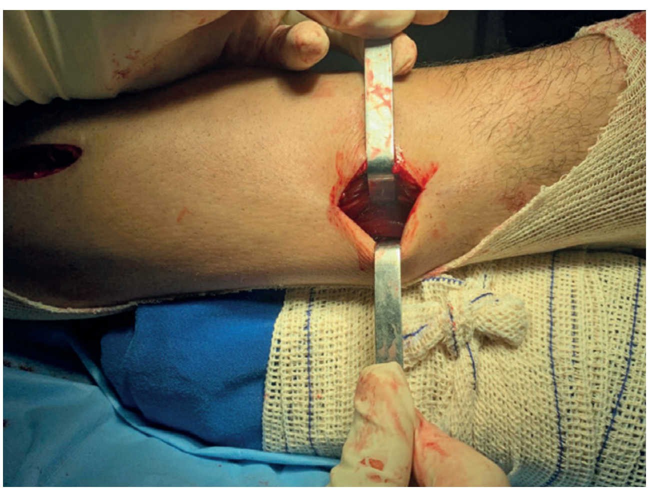

Figure 3. Medial incision showing the released fascia of the posterior compartment.

Figure 4. Photograph one week after operation showing the patient's progress, with full range of motion.

In the present report patient experienced chronic posterior pain during exercise and had attempted conservative treatment without success. Diagnosis was possible with the use of post-exercise MRI. The conventional leg MRI protocol usually presents normal results in the setting of CECS, and well-defined thresholds for MRI diagnosis are still missing. However, recent studies have attempted to validate established protocols. The use of liquid-sensitive sequences after physical exertion has shown high specificity and sensitivity in the diagnosis of CECS according to the intracompartimental-measured pressure[6,7].

Conservative treatment should be attempted for at least six weeks before surgery, but it is usually ineffective, unless the patient is willing to avoid the inciting activities[3,9]. A comparative study of conservative versus surgical treatment[3] showed that 77% of subjects in the surgical group were able to return to their previous activity level, in comparison to only 25% of patients in the conservative group.

Open fasciotomy has been considered the gold-standard treatment[3,4,8]. However, different techniques have been described for performing minimally invasive or even endoscopic treatment[2,4,8,9]. For our patient, surgical option was to use minimally invasive incisions and fasciotomy of the four compartments of the leg. The use of two incisions laterally allows a better visualization of the fascia and minimizes the risk of injury of the superficial peroneal nerve, one of the most common complications of this technique[4,9]. These incisions are made to release the anterior and lateral compartments. The medial incision is performed in the middle third of the leg, just posterior to the medial border of the tibia. Caution is taken to protect the saphenous vein and nerve, and the superficial and deep posterior compartments are released.

A systematic literature review has not shown statistically relevant differences between the results of minimally invasive treatment and endoscopic-assisted techniques, with satisfactory results above 80%[10]. However, the author points out that high-quality evidence is still lacking. Another review of the literature[4] shows good results with minimally invasive treatment, but with a considerable high incidence of complications such as nerve injuries. However, the abovementioned review mentioned only studies with single incision techniques.

The military population has been pointed out as having poorer results following CECS treatment[4]. Up to 27.7% of patients were unable to return to the previous activity level, and 44% of patients had persistent symptoms in a large retrospective review. Our patient worked in the military police and managed to return to his previous activity levels.

The CECS is a challenging pathology, and its diagnosis requires a high level of suspicion, especially in unusual presentations. The MRI is a useful noninvasive method for diagnosis. Minimally invasive fasciotomy has been shown to be an effective option of treatment, and the technique described in this article might reduce complications associated with other minimally invasive treatments described.

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Case Report

Total ankle arthroplasty with total talus implant printed by 3D printer

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Abstract

Describe a case of an aggressive talus tumor treated with total ankle arthroplasty with a patient-specific total talus implant printed on a three-dimensional (3D) printer. A 46-year-old female patient with a history of giant cell tumor treated in the past with partial resection of the talus and replacement with cement, evolving with progressive functional limitation eight years after the initial procedure. In the preoperative, the range of motion was 15° of flexion and 0° of extension, Visual analog scale (VAS) of 8, The American Orthopaedic Foot & Ankle Society (AOFAS) of 45, and the data compiled from the 36-Item Short Form Survey (SF-36) of 50%. The patient was submitted to total ankle arthroplasty with a patient-specific total talus implant printed on a 3D printer. The evaluation six months after the procedure showed a range of motion of 30° of flexion, 8° of extension, VAS of 2, AOFAS of 75, and the data compiled from the SF-36 were 75%. Weight-bearing anteroposterior and profile radiographs indicated that the alignment of the implants was maintained. Our study is the first patient-specific total ankle arthroplasty procedure with total talus implant described in the Brazilian literature. Patient-specific total ankle arthroplasty with total talus implantation is a technique that can provide pain relief, maintain movement, and improve patients' quality of life.

Level of evidence IV; Therapeutic study; Case report.

Keywords: Arthrosis; Bone avascular necrosis; Arthroplasty, Replacement, Ankle; Printing, three-dimensional.

Introduction

Several conditions can cause massive bone loss of the talus, such as avascular necrosis, comminuted fracture, infection, tumors, and failures related to a total ankle prosthesis. Avascular necrosis is the most common reason a talus cannot be reconstructed. Traditionally, pantalar arthrodesis with a structural bone graft has been the go-to salvage procedure for addressing irreparable talus lesions. However, functional limitations, non-consolidation, and patient dissatisfaction have led to the search for alternative treatments[1,2].

Patient-specific three-dimensional (3D) printing technology has recently created digitally engineered implants from a computed tomography (CT) scan. These titanium or chromium-cobalt implants expand the range so that surgeons can plan better, choose alternatives, and improve efficiency and results for several complex foot and ankle pathologies[1,3,4].

The purpose of this study is to describe a case of an aggressive talus tumor treated with total ankle arthroplasty with a patient-specific total talus implant printed on a 3D printer.

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

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Conflict of Interest: Daniel Baumfeld is Consultant/Speaker for Arthrex and Stryker. Caio Nery is Consultant/Speaker for Arthrex and Stryker. Tiago Baumfeld is Speaker for Medartis. **Source of funding:** None. **Date received:** September 15, 2024. **Date accepted:** October 25, 2024. **Online:** December 30, 2024.

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Case report

A case of a 46-year-old female patient with a history of pain and edema around the left ankle started eight years ago. At the time, radiographs of the ankle showed an expansive lytic lesion involving more than half of the talar body. The diagnosis after an incisional biopsy was a giant cell tumor(5). A resection of the tumor by anterior access followed by partial replacement of the talus with bone cement was then performed. Histopathology confirmed the diagnosis of a giant cell tumor. There was no radiological evidence of recurrence, and the patient could perform her daily activities partially, with progressive limitations during this period.

Recent imaging tests (radiographs and CT) showed severe tibiotalar arthrosis, with talar erosions at the site where the orthopedic cement was implanted and irreparable pantalar degeneration (Figure 1). The patient had disabling pain in the ankle when walking, limitation of daily life, and claudication.

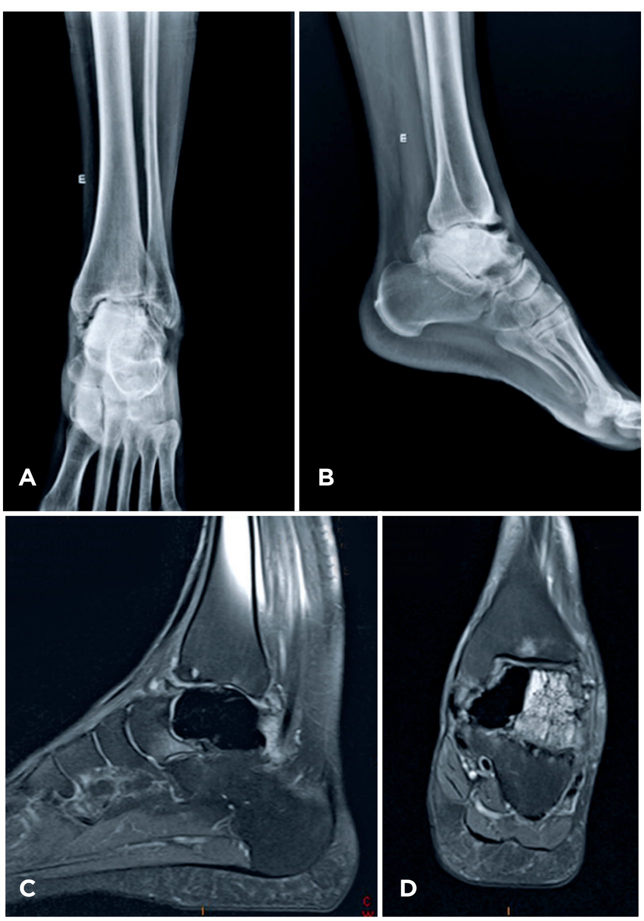

Figure 1. Recent images (radiographs and computed tomography) show severe tibiotalar arthrosis. A) Anteroposterior radiography of the ankle. B) Profile radiography. C) Coronal section computed tomography. D) Sagittal section computed tomography.

Ankle movement was limited, with 15° of flexion and 0° of extension. The visual analog scale (VAS) was 8, the American Orthopaedic Foot and Ankle Score (AOFAS) was 45, and the data compiled from the 36-Item Short Form Survey (SF-36) of 50% with functional data of 40%, energy of 65%, emotional of 72%, social of 62.5%, pain of 10%, overall health of 55%.

Preoperative planning

Comparative weight-bearing anteroposterior and profile radiographs, panoramic radiographs of the lower limbs, long posterior axial radiographs of the calcaneus and CT with bilateral 3D reconstruction of the ankles were performed. The DICOM file images were used to make the 3D implant. The contralateral CT was used as a reference for drawing the talus.

For 3D manufacturing and printing, DICOM file images allowed the design engineers to import CT scan data, segment the anatomy, and create volume reconstructions for 3D printing of the metallic implant (Figure 2). The metal chosen for printing was polished titanium with nitride coating. The model of the tibial implant and polyethylene that will be used must also be available so that the engineers and the manufacturer can adapt the printed talus to the proposed tibial component. The model Infinity prosthesis (Stryker Corporation, Michigan, USA) was used in our patient. The surgery team should be closely involved in the design process so that the implant's size follows the surgical planning. It is recommended that the supplying company send the surgeon an acrylic model of the printed talus to familiarize themselves with the size and approve the final print (Figure 3). Test implants of the same size as the definitive talus implant for the surgical procedure are also recommended to test the ligament balance before the definitive implantation.

Surgical technique

The patient was submitted to spinal anesthesia and venous sedation by the anesthesia team. A non-sterile thigh tourniquet was placed on the left side. Anterior ankle access of 8 cm was

Figure 2. Printed talus acrylic template.

performed. Once the tibiotalar and talonavicular joints were exposed, the osteophytes were removed from the distal tibia and the medial and lateral gutter. The tibia was prepped before talus removal to create a larger working area. The technical guide for the tibial portion of the Infinity ankle arthroplasty was followed, and the standard tibial size number 3 was selected. The tibial plafond cut was made 3 mm more proximal than a normal cut to accommodate the full talus.

After the tibial cut, the talar remnants and the talus cement were removed. During this part of the procedure, care was taken to perform all dissection of the capsule and ligaments inserted into the navicular and calcaneal tibia, preserving the soft tissue shell. The articular cartilage of the navicular and calcaneus were preserved. A fluoroscopic image was obtained to confirm that the talus had been removed completely.

After tibia implantation, the 3D total talus test was inserted for stability, movement, and alignment testing (Figure 4). The test polyethylene was inserted, and fluoroscopic images were obtained to evaluate the component size adequacy. Once the proper stability and alignment were confirmed, the test components were removed, and the final talus component size 3 was placed, followed by the polyethylene size 3/6 mm. It was followed by flat closure, dressing, and positioning of a splint in neutral.

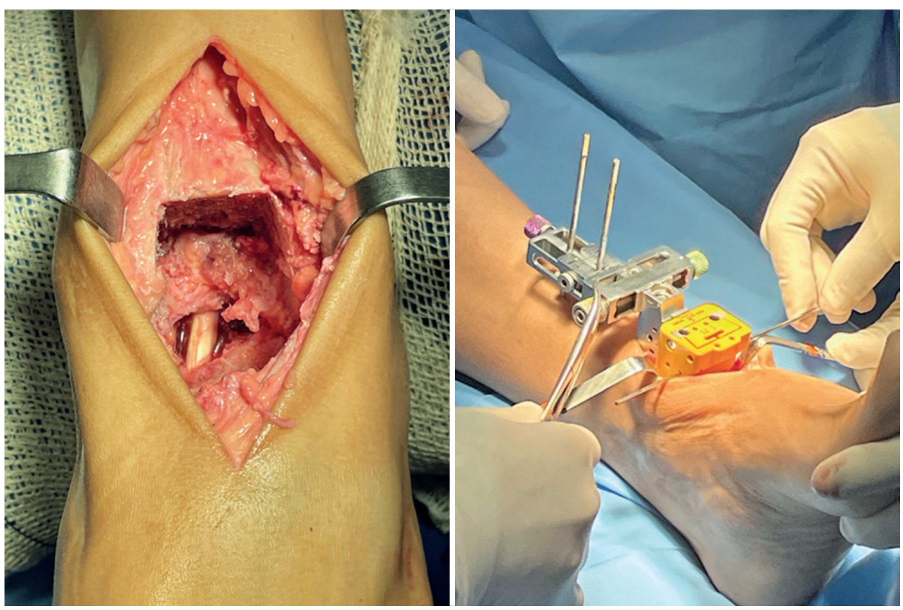

Figure 3. Ankle cuts already made and the process of the cuts.

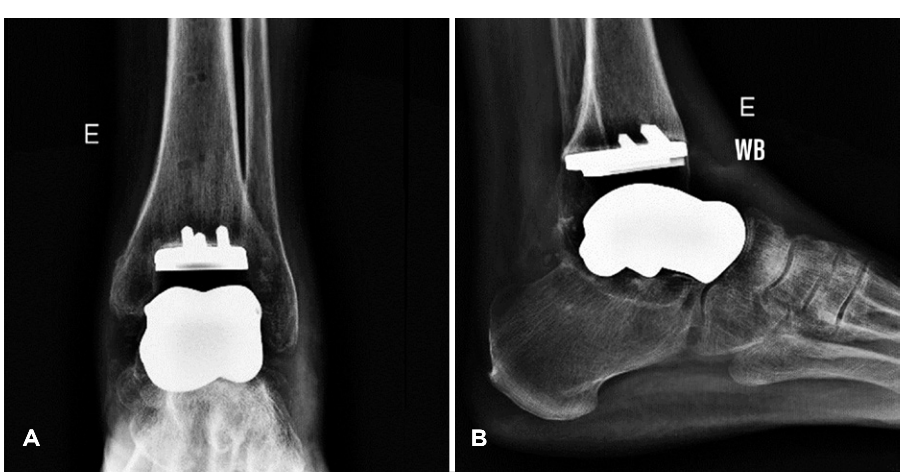

Figure 4. Radiographs showing the alignment of the implants were maintained. A) Anteroposterior radiography of the ankle. B) Profile radiography.

Postoperative period

The patient was kept for four weeks with a splint, which was changed weekly for inspection and wound care. The splint and dressings were removed at four weeks, and the patient was placed in an orthopedic boot with progressive weight-bearing for the subsequent four weeks. During this period, the patient was allowed to remove the boot to perform ankle range of motion exercises. The boot was discontinued at eight weeks, and formal physiotherapy was started. In her most recent follow-up, with six months of evolution, the patient walked without gait support. Clinically, it had 30° of flexion and 8° of extension. She presented VAS of 2, AOFAS of 73, and SF-36 of 75% with compiled and descriptive data with functional data of 70%, energy of 85%, emotional of 76%, social of 75%, pain of 67.5%, overall health of 65%.

Weight-bearing anteroposterior and profile radiographs indicated that the alignment of the implants was maintained (Figure 4).

Discussion

The first patient-specific talus implants were reported in the literature in the 1990s as an alternative to arthrodesis procedures(2,6,7). This first-generation implant replaced only the talar body made with ceramic or stainless steel, with pins cemented to the talus neck to provide initial fixation. Despite some initial success, there were concerns regarding the loosening and sinking of the prosthesis as well as subtalar erosion(8). As a result, in the early 2000s, second-generation ceramic and metal talar body prostheses were developed without pins and with more anatomical subtalar curvature. However, the loosening of the prosthesis and the collapse of the talus head continued to affect the survival of these implants(3,6).

In irreparable talar losses and tibial arthrosis cases, total ankle arthroplasty with total talus implantation is needed. Few cases like this have been published in the literature, but it is suggested that total arthroplasty results in better clinical outcomes than isolated talus replacement(2-4,6,8).

Kanzaki et al.(9) performed 22 procedures with talus made of ceramic, where they demonstrated an improvement in range of motion from 26.6° to 46.5°. Complications reported included one intraoperative fracture of the medial malleolus, two postoperative fractures of the medial malleolus, and three cases of delayed wound healing. Some authors report that metal talus printing is more beneficial and has a lower complication rate than ceramic due to the greater ease in performing metal 3D printing, lower component fracture rate, and greater assertiveness in performing specific implants for the patient(9).

Kurokawa et al.(10) published a retrospective comparative analysis of ten patients submitted to total talus replacement alone compared to total talus replacement combined with total arthroplasty. At a median follow-up of 58 months, the Japanese Society for Surgery of the Foot (JSSF) functional score for the hindfoot was better for the group in which surgery was combined (44-89) compared to replacement alone (49-72). The authors concluded that combined surgery resulted in better short-term clinical outcomes(10).

Conclusion

Our study is the first patient-specific total ankle arthroplasty procedure with total talus implant to be described in the Brazilian literature. It is hoped that with the popularization of ankle arthroplasty and its range of implants, more surgeons can be trained to perform the procedure, and more patients can benefit from it.

Patient-specific total ankle arthroplasty with total talus implantation is a technique that can provide pain relief, maintain movement, and improve patients' quality of life.

Authors' contributions: Each author contributed individually and significantly to the development of this article: DSB *(https://orcid.org/0000-0001-5404-2132) Performed the surgeries, data collection and approved the final version; BDM *(https://orcid.org/0000-0003-2178-5671) Performed the surgeries, data collection and approved the final version; JAVS *(https://orcid.org/0000-0002-6321-9566) Conceived and planned the activities that led to the study and approved the final version; CASN *(https://orcid.org/0000-0002-9286-1750) Conceived and planned the activities that led to the study and approved the final version; PCM *(https://orcid.org/0009-0008-0505-1145) Interpreted the results of the study, participated in the review process and approved the final version; BMGM *(https://orcid.org/0009-0002-4821-1061) Interpreted the results of the study, participated in the review process and approved the final version; TSB *(https://orcid.org/0000-0001-9244-5194) Performed the surgeries, data collection and approved the final version; HMMR *(https://orcid.org/0009-0002-0738-9103) Wrote the article, interpreted the results of the study, data collection and statistical analysis iD.

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