Current Concepts in Treatment of Ligament Incompetence in the Acquired Flatfoot Q4

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KEYWORDS

• Ligament insufficiency • Flatfoot • Deltoid ligament • Spring ligament
• Tibiocalcaneonavicular ligament • Flatfoot algorithm

KEY POINTS

- Flatfoot is a complex deformity with multiligamentous insufficiency.
- Skeletal and soft tissue reconstruction must be considered when considering operative intervention.
- Ankle, hindfoot, and midfoot must be considered in the analysis when planning a flatfoot reconstruction.
- Tibiocalcaneonavicular ligament reconstruction should be considered in almost every flexible flatfoot case.

INTRODUCTION

Adult-acquired flatfoot consists of a flattened foot, with a combination of deformities, such as a flat arch, valgus hindfoot, and varying degrees of forefoot abduction. The Q7 deformity can vary in severity and location and often results in a progressive deterioration of foot function. Historically considered because of a posterior tibial tendon failure, a combination of ligament insufficiencies has been shown to be present, which explains the multiple apices of deformity generally present in flatfeet cases.[1] The multiple sites of deformity explain the wide variation on its clinical presentation.[2] Pain initially may be present along the medial aspect of the ankle joint, or in relation to the posterior tibial tendon, which becomes inflamed because of its continued pull of trying to hold the hindfoot and medial arch. Later in its natural history, flatfoot pain may propagate along the medial arch itself and even progress onto the lateral aspect of the ankle because of subfibular impingement. In this article, the authors analyze the

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current concepts in treatment of ligament incompetence of the acquired flatfoot, considering the skeletal actions recommended to achieve deformity correction and the soft tissue reconstructions to repair or strengthen the damaged ligaments. The flatfeet history, study, and diagnostic aspects are out of the scope of this article.

BIOMECHANICAL BACKGROUND

One of the first manifestations of flatfoot deformity is a decrease in the medial longitudinal arch.[3] To observe a loss in medial arch height, the main tissues capable of supporting the arch must become involved, that is, the plantar fascia, the spring ligament, and the tibialis posterior tendon.[4] Furthermore, in this last study, it was also shown that the posterior tibial tendon itself is not able to support the plantar arch itself, which supports the concept of a multiple ligament deficiency pathologic condition. Besides statically becoming a flatfoot, kinematic alterations, such as calcaneal eversion, internal tibial rotation, and abduction of the forefoot, will occur.[5] Hindfoot eversion will further increase the chance of deformity progression, as the Achilles tendon becomes a deforming vector/force. Once talocalcaneal rotation happens, more stress will be translated onto medial structures, such as the deltoid, spring ligament, and the talonavicular joint.[6] A recent study showed that there is a strong connection between the navicular and medial cuneiform, which highlights the multiple ligament connection between the medial column and the hindfoot.[7] The windlass mechanism produced by the plantar fascia dynamically stabilizes the medial column through its attachment to the calcaneus and forefoot (ie, sesamoid bones, plantar plates of lesser metatarsals, plantar fat pad). In the propulsive phase of gait, the windlass mechanism shortens the plantar aponeurosis, which helps to create a rigid medial column, necessary for toe-off.[8] For this important function to happen, the windlass mechanism relies on healthy functioning joints and ligaments. Therefore, any incompetence of the medial column joints may result in a deficiency of this mechanism and loss of function and improper gait mechanics.

Multiple classifications have been proposed to provide guidelines in the analysis and treatment of acquired flatfeet.[9] They are mainly based on foot position and deformity flexibility. Radiographic analysis considers axial weight-bearing radiographs, which provide alignment views useful to measure the distance between the mechanical axis of the tibia and the point of contact between the calcaneus and the floor.[10] Foot anteroposterior (AP) and lateral weight-bearing views provide useful information relative to the talocalcaneal rotation, talonavicular relation, and any medial column sag or instability present. The authors prefer to analyze flatfeet deformities from a biomechanical perspective, from proximal to distal, considering the location of the apex of the deformity, and thus propose treatment depending on where the apices are, and how severe the deformity is. Ligament reconstruction is considered whenever the deformity is flexible, with or without arthritis. Flexible deformities are defined by the authors as any clinical malalignment that can be corrected actively by the patient, or passively by the physician (considering intraoperative manipulation, usually controlled by fluoroscopy). In this way, the proposed algorithm for analysis for reconstructive procedures in flexible flatfoot is presented in Fig. 1.

FLEXIBLE FLATFOOT INSTABILITY ANALYSIS

Supramalleolar Apex

The analysis starts at the supramalleolar region, where the coronal and sagittal plane alignment must be analyzed in search of any deformity, being normal values of the distal anterolateral angle of the tibia between 88° and 95° and the anterior distal angle

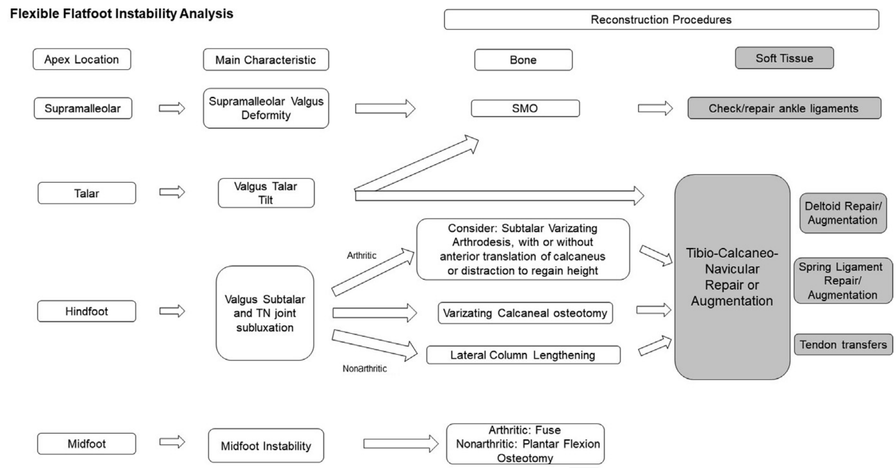

Fig. 1. Algorithm for analysis of flexible flatfeet deformities. In the columns from left to right are the apex location of the deformity, the main radiological characteristic, the bone reconstruction procedures, and the soft tissue reconstruction procedures (*gray shading*). SMO, ; TN, . Q15

of the tibia between 78° and 82°.[11,12] Corrective supramalleolar or even intraarticular osteotomies can be planned when any malalignment is found in this region (**Fig. 2**).

Talar Apex

The talus should be evaluated in its mortise, and no tilt should be found in relation to the pilon. The talar tilt angle can be measured as the difference between the distal lateral angle of the tibia and the tibiotalar angle, measured between the mechanical axis of the tibia and the most superior surface of the talus. The normal value is 0° to 4°. If altered, it means either there is an asymmetric wear of the cartilage, that is, a localized arthrosis of the ankle joint,[13] or there is a medial deltoid ligament instability of the ankle joint.[2] When correcting a talar tilt, after corrective osteotomies or arthrodesis is made, if the talus maintains a tilted situation inside the ankle joint and imaging studies confirm isolated damage of the deltoid ligament, a reconstruction of the deltoid complex should be considered.

Hindfoot Apex

Whenever there is a loss of height at the hindfoot, the talus may rotate or tilt because of the loss of intrinsic stability, showing signs of peritalar instability.[14] Instability may manifest in diverse forms, such as coronal deviation in varus or valgus, sagittal deformities, such as plantar flexion or dorsiflexion, and finally, axial deviation, such as internal or external rotation.[15] The reader is referred to the corresponding article in this issue to learn more about this topic (see table of contents). More distally, the subtalar joint can compensate 58% and 35% of the varus and valgus deviation, respectively, at the ankle joint.[16] Deformity at the subtalar joint is fundamental to evaluate, as it may be part of a peritalar instability or already be one of the components of a rigid flatfoot deformity. One way to measure subtalar malalignment uses the hindfoot alignment angle. This angle is defined by the intersection between the tibial and calcaneal axis[17] (**Fig. 3**). Hindfoot malalignment represents a coronal rotation of the talus over the calcaneus, specifically, an external rotation of the calcaneus in relation to the talus.[3] As the

Fig. 2. Full-length leg radiograph of patient where, on the left side, a clear valgus orientation of the distal tibia is observed, generating a supramalleolar valgus deformity.

tibia internally rotates and the calcaneus everts, more pressure is translated onto the talonavicular joint, and an abduction deformity of the forefoot over the hindfoot may occur.[6] If the flatfoot deformity increases, at this point, a more severe ligament insufficiency of the medial ankle and midfoot is expected to be present. As the medial ligament insufficiency progresses, a multiplanar instability of the ankle develops, because of erosion and wear of the calcaneofibular ligament.[13] Because of this, a combined ligament repair should be performed in these cases. A recent anatomic study analyzed the medial ankle ligament complex as a functional unit and defined the largest component of the deltoid as the tibiocalcaneonavicular ligament, which apparently includes portions of the tibionavicular, tibiospring, and tibiocalcaneal ligaments.[18] In summary, whenever the talus is malrotated over the calcaneus, after corrective osteotomies or arthrodesis are made, a tibiocalcaneonavicular reconstruction and a lateral ligament repair or reconstruction may be considered.

Midfoot Apex

Medial column stability is crucial to evaluate in flatfoot patients. On lateral weightbearing radiographs, any loss of the medial longitudinal arch must be measured,

Fig. 3. Bilateral axial hindfoot radiograph showing the hindfoot alignment angle, between the tibia axis and the calcaneal axis. In this example, a clear increase in deformity is seen on the left side of the picture.

that is, any loss in height between the lateral and the medial column. Any collapse seen on radiographs indicates insufficiency of the pertaining ligaments of that joint (**Fig. 4**). Collapse can occur through the talonavicular, naviculocuneiform, cuneometatarsal, or combination of these joints.[9] The most named ligament in this area is the spring ligament, frequently damaged in flatfeet, and even isolated tears of it can produce a flatfoot condition.[19] This condition constitutes what has been named a forefoot-driven hindfoot valgus deformity, where no real pathologic condition is found in the hindfoot, which may explain the pathologic valgus, but instead a pathologic medial column is present, allowing the midfoot and forefoot to lose height, thereby pulling the hindfoot into valgus. A medial column insufficiency with a sag at the talonavicular or naviculocuneiform joint, after corrective osteotomies or arthrodesis, may be amenable for reconstruction with spring ligament repairs or naviculocuneiform repairs.

Fig. 4. Lateral weight-bearing foot radiograph of a symptomatic flatfoot patient. Notice the abnormal Meary angle drawn between the axis of the talus and the first metatarsal bone. No clear sag is seen in any specific joint, but rather a diffuse loss of Meary angle.

FLEXIBLE FLATFOOT INSTABILITY TREATMENT

No published algorithm evaluates the apex of deformity in a flatfoot condition in a proximal-to-distal manner. The authors think that a proximal-to-distal analysis helps to organize better the treatment alternatives, from a skeletal and soft tissue point of view. Depending on the level of the deformity, different reconstruction procedures can be applied, dividing them into bone procedures or soft tissue procedures (see Fig. 1). The authors briefly analyze the different treatment alternatives depending on the apex of the deformity location, first naming the skeletal procedures and then the soft tissue repair or reconstruction. In this issue, separate articles include deltoid and spring ligament repair. Therefore, in this article, the authors focus on hindfoot correction through a combined deltoid and spring ligament approach, which they name as the tibiocalcaneonavicular ligament repair and reconstruction.

Supramalleolar Valgus Deformity

Bone reconstruction

A supramalleolar osteotomy (SMOT) is well suited to address almost any kind of supramalleolar deformity and intraarticular deformities, even where asymmetric arthrosis is present. An example of a supramalleolar valgus deformity is presented in Fig. 2. In cases of asymmetric arthrosis of the ankle joint, more cartilage loss can be found in the lateral aspect of the ankle joint, on either the talar or the tibial side, producing an intraarticular valgus deformity (Fig. 5). In these supramaleolar deformities, a

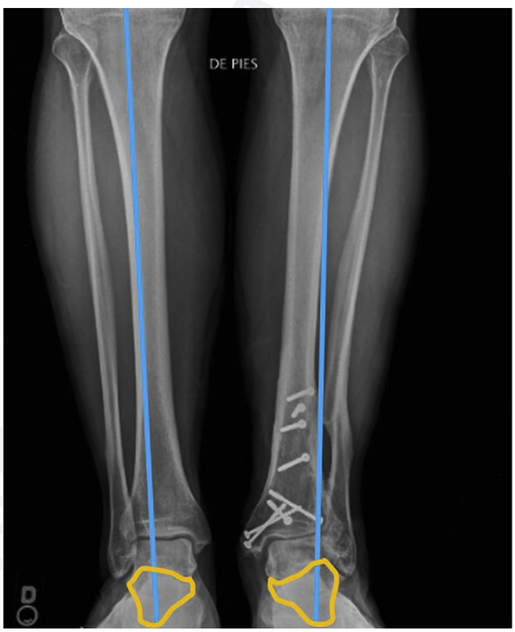

Fig. 5. AP weight-bearing leg radiographs, in which an old distal tibia fracture can be noted on the left leg (*right side of the image*). Note the intraarticular valgus alignment of the talus, owing to an asymmetric posttraumatic ankle arthrosis where more damage was sustained on the lateral aspect of the joint. The mechanical axes are drawn on each leg for comparison (*blue lines*), and the calcaneus silhouettes are depicted as orange lines. Note the lateralization of the weight-bearing axis of the left leg, where the blue line crosses the ankle joint at the level of the tibiofibular joint.

varizating SMOT is generally recommended, with a medial tibial wedge resection considering the whole foot for final balance[13] (Fig. 6). Q8

Soft tissue reconstruction

As commented previously in the instability analysis section, these patients frequently develop a multiplanar instability of the ankle. Because of this, a combined ligament repair should be performed. The medial ligaments must be examined, as continuous stress may have deteriorated their insertion. Relevant to this damage is to correctly identify the insufficient components, and most frequently the tibionavicular and tibiospring components are compromised.[20] In these cases, reattachment with bony anchors placed at the navicular and at the distal tibia is recommended. The lateral ligaments must be tested under fluoroscopy, and if lax, their insufficiency should also be addressed at the same time of the osteotomy.

Valgus Talar Tilt

Bone reconstruction

Almost every talar tilt presents some amount of asymmetric ankle cartilage damage, which allows the talus to tilt inside the mortise. Whenever the talus is tilted into valgus inside the mortise, a peritalar instability should be suspected. Peritalar instability has been analyzed by Hintermann and colleagues[13,14] and is analyzed elsewhere in this issue. Importance must be given to it, and the authors recommend the reader go through Hintermann's analysis for valgus cases (see table of contents). If there is arthrosis present at the peritalar joints, regaining stability through subtalar arthrodesis, triple arthrodesis, or subtalar distraction arthrodesis is a definitive solution that will regain hindfoot height and through that regain tension of the ligaments and soft

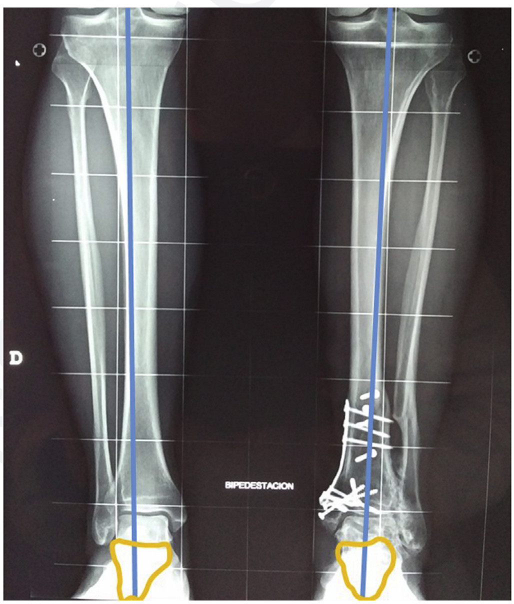

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Fig. 6. AP weight-bearing leg radiographs of the same patient shown in Fig. 5. A varizating SMOT was performed on the left leg (*right side of the image*) achieving a medialization of the weight-bearing axis (note where the *blue line* crosses the ankle joint). A good clinical result was achieved and lasted for 10 years. Q16

tissues, improving ankle stability.[21–23] Final alignment is achieved adding a varizating SMOT (Figs. 7 and 8). If no arthrosis is present at the peritalar joints, valgus talar tilt can be managed solely through a varizating SMOT. In these selected cases, after performing the SMOT, intraoperative fluoroscopy is mandatory to evaluate the correct realignment of the talus inside the mortise, adding soft tissue reconstructions as needed.

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Soft tissue reconstruction. It must be remembered that isolated deltoid ligament damage is seldom present, and the authors recommend almost always performing combined tibiocalcaneonavicular repairs or reconstruction (see next section). For isolated deltoid ligament damage, the authors refer the reader to review the topic in this issue (see table of contents).

Subtalar Valgus and Talonavicular Joint Deformity

Bone reconstruction

For a subtalar joint valgus deformity to appear, it has been already mentioned that a talocalcaneal rotation must occur, which includes an internal rotation of the talus with a secondary talonavicular incongruency and valgus deformity of the hindfoot. Different bony procedures have been designed to derotate the talus in relation to the calcaneus and decrease medial soft tissue strain, namely subtalar arthrodesis, and varus producing calcaneal and lateral column lengthening osteotomies. When there is already a symptomatic arthritis at the subtalar joint, a subtalar corrective arthrodesis is the treatment of choice, which will correct rotation, eversion, and valgus malalignment of the calcaneus in relation to the talus.

A subtalar corrective arthrodesis must correct all the components of the deformity, including the external rotation of the calcaneus in relation to the talus, the consequent valgus of the subtalar joint, and the loss of hindfoot height. The apex of the hindfoot deformity in a flatfoot case lies on the posterior facet of the subtalar joint, which

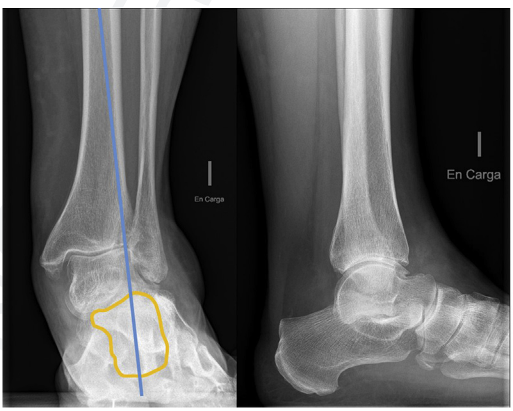

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Fig. 7. AP weight-bearing ankle radiograph of a severe flatfoot case with valgus ankle, valgus hindfoot, and peritalar instability. The blue line represents the mechanical axis of the limb, which crosses the ankle join at the tibiofibular joint. The calcaneus silhouette is represented with an orange line. See the lateral ankle view, where a subluxation of the talonavicular and subtalar joint can be seen. In this case, a triple arthrodesis could align the hindfoot but would not correct the valgus ankle. To realign the mechanical axis, an SMOT must be added.

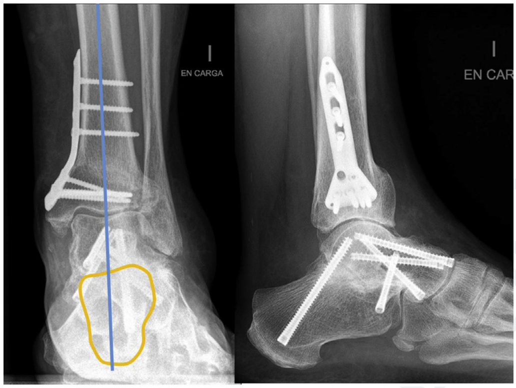

Fig. 8. AP weight-bearing ankle radiographs of the same patient shown in Fig. 7. The blue line now intersects the ankle joint line in the middle of the joint. The stability and height of the hindfoot were restored thanks to the arthrodesis. Note that although a varizating SMOT was added, the ankle joint line still remains in a slight valgus. This exemplifies how important it was to add an SMOT in this case, as a triple arthrodesis alone would have been completely insufficient. It also shows the difficulty in achieving excellent alignments in these cases.

corresponds to the center of rotation of the subtalar joint. In relation to this apex, the talus rotates on top of the calcaneus, falling into valgus, losing height, and creating a midfoot deformity. A corrective arthrodesis therefore should be performed, producing an internal rotation of the calcaneus in relation to the talus. Achieving this derotation corrects the hindfoot height and valgus, as the talus recovers its original position, and may improve ankle stability because of medial deltoid ligament retensioning. The authors recommend, when performing a subtalar arthrodesis, to focus intraoperatively in derotating the talus on the calcaneus. This maneuver is performed using a lamina spreader placed against the floor of the sinus tarsi and against the anterolateral process of the talus (Fig. 9). A distraction between the 2 points pushes the talus

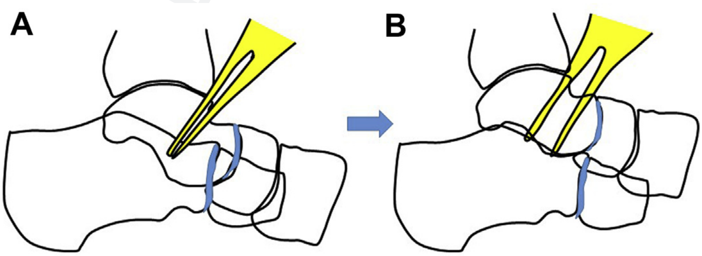

Fig. 9. (*A*) A flatfoot hindfoot, from the lateral view. The maneuver to derotate the talus in relation to the calcaneus uses a lamina spreader, drawn in the image as a yellow figure. The arms of the spreader are placed against the floor of the sinus tarsi distally and plantarly, and against the anterolateral process of the talus, proximally and dorsally. (*B*) The lamina spreader is shown opened, and the derotation of the talus on the calcaneus is evident. Now the talus sits on top of the calcaneus, and because of the distraction, the calcaneus is brought forward in relation to the talus, thus creating a lateral column lengthening effect. Note the chopart joint, depicted as a blue area, as it changes from *A* to *B*, becoming well aligned in panel *B*.

backwards and rotates it externally, achieving a derotation and also a relative lengthening of the lateral column, which also assists in correcting any abduction deformity at the talonavicular joint (Figs. 10–13).

If the subtalar joint is not arthritic, a medial translational calcaneal osteotomy may be of use. Caution must be taken if there is any concern about peritalar instability. In some cases, because of some cartilage loss at the ankle joint, a varizating calcaneal osteotomy may create a zigzag effect, which has been described where an increase in the valgus orientation of the hindfoot may occur.[24] Finally, the last skeletal option to correct a subtalar and talonavicular malalignment is a lateral column lengthening. This procedure can be performed through a classic anterior process, calcaneal osteotomy, or through a step cut osteotomy of the calcaneus.[25] The correction of the talocalcaneal rotational deformity through a lateral column lengthening occurs through the talonavicular joint, where the calcaneus pushes forward the lateral column, thereby correcting the abduction deformity and secondarily pushing the talus over the calcaneus in a corrected position. It has been shown that lengthening the calcaneus is highly effective to correct abduction,[26] and its correction capacity has been measured.[27] A limit between 4 and 8 mm of lengthening has been proposed[26] because of concerns of hindfoot rigidity, lateral column overload, and inferior functional outcomes observed after excessive lateral column lengthening. These concerns highlight the difficulty in achieving a deformity correction beneficial for the patient. It may be possible to avoid overcorrection through lateral column lengthening restricting its use, indicating it after certain deformity limit, for example, 50% of talonavicular uncoverage. For cases under this limit, a combined deltoid and spring soft tissue retensioning and reconstruction could be beneficial.[9,28] This last approach is the one the authors recommend, and it is detailed in the next section.

Soft tissue reconstruction

Tibiocalcaneonavicular reconstruction. A complex combination of soft tissue damage must be assumed to be present in these cases, that is, the calcaneonavicular (spring)

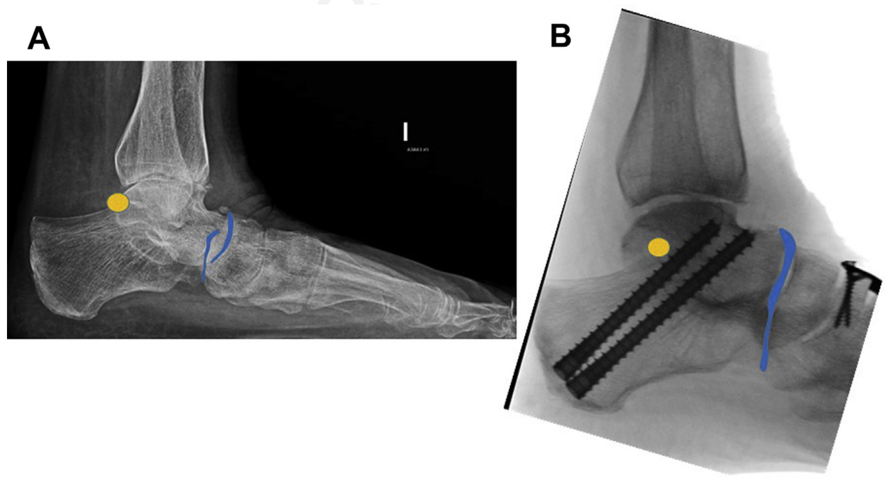

Fig. 10. (*A*) Intraoperative fluoroscopy depicting the same maneuver shown in Fig. 9. The chopart joint is delineated with blue lines. The yellow dot is sitting on the most posterior aspect of the calcaneus. (*B*) Note how after the derotation arthrodesis, the chopart joint now is well aligned and how the calcaneus now lies anteriorly displaced in relation to the talus.

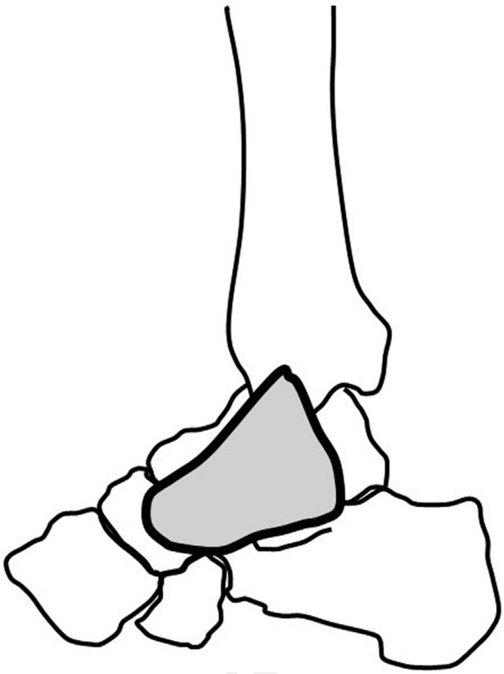

Fig. 11. The medial hindfoot, where a triangle was superimposed over the area between the tibia, calcaneus, and navicular. This triangle represents the tibiocalcaneonavicular ligament.

ligament, posterior tibialis tendon, deltoid ligament, plantar fascia, short and long plantar ligament, joint capsules, and intrinsic foot muscles, among others. Of all these structures, the most important is the plantar fascia, which provides 25% of arch stiffness.[29] The reconstruction of the spring, deltoid, or any other ligament in isolation will probably not be enough to support the longitudinal arch and medial mid-rearfoot structures, given that medial ligaments work as a unit.[18] The proposed reconstruction should include every damaged medial structure and not just segments of it. This is where the tibiocalcaneonavicular reconstruction plays a role. This reconstruction

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Fig. 12. Intraoperative picture of medial surgical approach to the hindfoot, between the medial malleolus and the navicular bone, identifying the flexor hallucis longus in order to locate the sustentaculum tali. *Courtesy of* Dr Anish R. Kadakia MD, Chicago, Illinois.

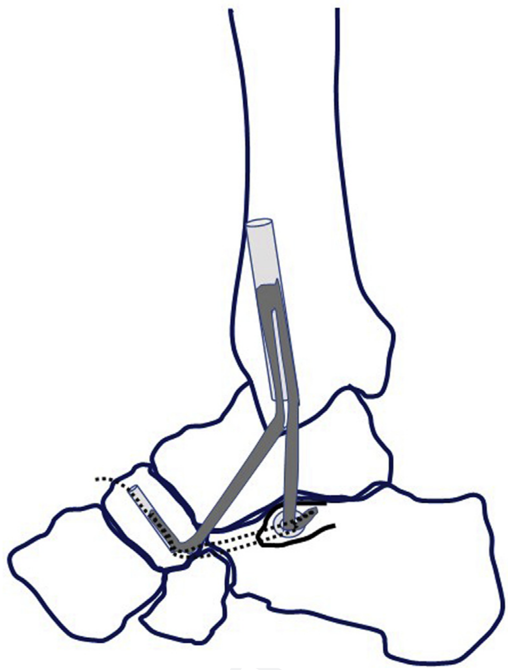

Fig. 13. The medial hindfoot, where the reconstruction of the tibiocalcaneonavicular ligament is represented. The graft is represented as a tubular structure between the tibia, sustentaculum tali, and navicular. A suture tape is represented as a dotted line structure between the sustentaculum tali and navicular.

closely resembles the whole medial rearfoot ligament complex: tibiocalcaneal, tibiospring, tibionavicular, and calcaneonavicular ligaments (see Fig. 5). There are some publications regarding this combined comprehensive reconstruction. In 2010, Williams and colleagues[30] compared different spring ligament reconstructions, namely, a calcaneonavicular and a deltoid-navicular configuration. The deltoid-navicular reconstruction was able to correct more degrees of midfoot abduction than the calcaneonavicular one. This cadaveric study was later supported by a finite element analysis in which a reconstruction from the medial cuneiform to the medial malleolus was the best option for controlling midfoot abduction.[31] In 2014, Baxter and colleagues[32] performed a study that showed that a tibionavicular reconstruction was better than a spring ligament reconstruction in restoring normal foot kinematics. To the best of the authors' knowledge, Grunfeld and colleagues[33] in 2016 were the first authors to report a surgical technique for the combined reconstruction of the deltoid and spring ligament. They described an allograft technique attached to the medial malleolus and using 2 limbs to have attachments at the sustentaculum tali and at the navicular. One year later, Patel and colleagues[28] described another combined reconstruction using synthetically augmented grafts on tibionavicular and tibiotalar directions, with good clinical results in a small series of patients. A reinforcement of native deltoid and spring ligaments with synthetic tape has also been published, that is, tibiotalar, tibiocalcaneal, and calcaneonavicular, with good initial results.[34] In 2019, Brodell and colleagues[35] analyzed Grunfeld's technique and added a modification that included a limb specifically for the spring ligament using tendon allograft. This modification has the advantage of reconstructing the whole medial ligament structures with an allograft, including the calcaneonavicular segment. This modification is the most complete medial ligament reconstruction published nowadays.

The authors' current recommendation is to perform a comprehensive reconstruction, including the tibionavicular, tibiocalcaneal, and calcaneonavicular ligaments for flexible flatfoot, in a similar fashion as Brodell has published. This reconstruction has a triangular shape that consolidates the hindfoot and midfoot medial soft tissue wall. Three tunnel points of fixation are recommended: one on the medial malleolus exiting laterally at the tibia for better fixation; one at the navicular tuberosity (tunnel in a plantar-dorsal direction); and one at the sustentaculum tali (exits laterally at the calcaneus). Whether tendon (auto or allograft) or synthetic augmentation is used, it depends on the native ligament's quality. When no ligament degeneration exists and insufficient but present ligaments are the case, an augmentation using suture-tape synthetic material is recommended (ultra-high-molecular-weight polyethylene, UHMWP) in addition to osseous procedures. If ligamentous degeneration exists, or no ligaments are present whatsoever, a reconstruction using a tendon allograft (peroneus longus, for example) or autograft (gracilis, semitendinosus) is recommended. For these reconstructions, a synthetic augmentation in addition to the tendon is the ideal construct. This combination of tendon graft and synthetic material avoids the tendon graft lengthening that inevitably occurs over time.

The surgical technique recommended by the authors (performed at the end of all osseous procedures) is described as follows:

The approach is from the medial malleolus tip to the naviculocuneiform joint. Expose and identify medial malleolus tip, tibialis posterior, and navicular tuberosity (see Fig. 6). Identify ligaments sufficiency and tibialis posterior degeneration. If a tendon allograft will be used, measure its width to choose the appropriate drill bit. The recommended tendon width is 4 to 5 mm, and the minimum recommended length is 25 cm. Perform the medial malleolar tunnel, starting at the malleolar tip in 45° of superolateral direction, until the lateral tibial cortex is crossed. At the navicular tuberosity, drill from inferomedial to superomedial. At the sustentaculum tali, start drilling 5 mm below the articular surface in 15° of plantar inclination (to avoid subtalar joint penetration) until the lateral calcaneal cortex is breached. The tibial tunnel should be 3 mm bigger than the tendon width, given that a folded tendon will be inserted through these tunnels. Suture each tendon end in a Krackow fashion or using a suture loop. Keep the tendon under tension at a side table for 5 minutes.

Start by traversing 1 tendon end through the calcaneal tunnel and transiently secure the sutures laterally at the calcaneus with a clamp. Then, insert the other tendon end through the navicular tunnel from plantar to dorsal. At least 1 cm of each tendon end should fit inside the calcaneal and navicular tunnels. Leave the sutures exiting laterally at the calcaneus and dorsally at the navicular clamped for later tendon tensioning. Finally, fold and suture the tendon remnant on a suture loop attached to a suture button (anterior cruciate ligament button can be used). Insert this button through the tibial Q12 tunnel. Make a 2-cm approach laterally at the tibia for suture-button retrieval. Apply light tension to the tendon graft by pulling at the button sutures. Make sure both tendon ends are still in their respective tunnels. Secure this button by 3 double knots at the lateral tibia. Insert an interference screw at the tibial malleolus tunnel for double graft fixation. Proceed then by inserting 1 end of a suture-tape material (UHMWP) into the sustentaculum tali tunnel and the other into the navicular. The suture tape emulates the spring ligament. Now, use an interference screw at the navicular to fix the suture tape and tendon graft while applying tension to the tendon graft. Then, focus on the calcaneus tunnel. Apply tension to the suture tape and tendon end at their exit through the lateral calcaneus wall, while an assistant holds the foot in the neutral position. Use a button (at the lateral calcaneal wall) and an interference screw at the sustentaculum tali for double graft fixation. Finally, reinforce the whole tendon allograft with a nonresorbable suture (UHMWP material). This reinforcement will give a more rigid structure to the whole tendon graft, avoiding tendon lengthening (see Fig. 7). In relation to tendon transfers, the authors do not recommend resecting the tibialis posterior tendon, which is commonly degenerated. Instead, the authors use the distal stump of the posterior tibialis tendon to anchor the flexor digitorum longus (FDL) tendon against it. They anchor it using a side-by-side tenorrhaphy with nonabsorbable sutures, pulling the FDL tendon distally in maximum tension.

The authors prefer this reconstruction variation over the Brodell method, because for the Brodell and colleagues' technique, an 8- to 10-mm tunnel is needed at the sustentaculum tali to be able to fit both tendon ends. For the authors' patient population, this tunnel size could jeopardize the sustentaculum tali integrity. The recommended reconstruction needs a 5-mm calcaneus tunnel, which will not weaken the sustentaculum tali structure. To the best of the authors' knowledge, Brodell and colleagues are the only investigators with published results using a tibiocalcaneonavicular ligament reconstruction.[35] They reported 12 flatfeet patients with advanced deformity that underwent the aforementioned ligament reconstruction, with a 24-month average follow-up period, showing excellent clinical outcomes and radiographic improvement.

Midfoot Instability

Bone reconstruction

When trying to pinpoint a precise apex of deformity along the medial arch, this is not possible most of the time. On weight-bearing lateral foot radiographs, a diffuse medial column sag is generally present. Addressing medial arch instability through fusions may not be the best option, as joint-preserving surgeries are preferable in flexible nonarthritic flatfoot patients. A finite element study was presented recently that showed that a naviculocuneiform fusion led to increased stress on the spring ligament, which supports the idea of avoiding fusions in this area.[36] Classically residual medial column instability has been addressed through a dorsal opening wedge osteotomy of the medial cuneiform. It has been shown that caution should be undertaken when performing this procedure, as excessive plantar flexion does not correlate with good functional outcomes.[26] Precise calculations have been published to know how much of a correction of the cuneiform morphology will be achieved with the osteotomy.[37] Relative to the last component of the medial column, that is, the tarsometatarsal joint, if there is additional involvement with a hallux valgus deformity, a tarsometatarsal arthrodesis will be an effective way of addressing both deformities.[9] If no additional deformity is present, the authors recommend performing tibiocalcaneonavicular soft tissue reconstructions to avoid fusions on the medial column. If there are imaging or intraoperative findings that suggest isolated spring ligament damage, isolated spring ligament repair can be performed.

Soft tissue reconstruction

The spring ligament repair is addressed elsewhere in this issue, and the readers are strongly encouraged to look at the corresponding article (see table of contents).

Tendon transfers

Although it is not discussed in this article, for most cases where a complete medial repair is performed, a tendon transfer is recommended. Frequently, an extensive tibialis posterior tendon degeneration is present in flatfeet patients. An FDL transfer is frequently used to reinforce or to replace the tibialis posterior. The authors do not usually resect the tibialis posterior, but they do shorten it. The FDL transfer is sutured in a side-to-side fashion to the distal tibialis posterior tendon stump. The tendon transfer is performed after the tibiocalcaneonavicular reconstruction is finished.

SUMMARY

Flatfoot deformity continues to be a challenging problem. Its various clinical presentations, deformity components, and severity contribute to its complexity. The ligament incompetence responsible for this complex deformity is multifactorial, comprising morphologically different ligaments, such as the tibio-spring, tibionavicular tibiocalcaneal, and spring ligament, besides the plantar fascia and posterior tibial tendon. Recently, a more functional division of the previously named ligaments has been published, naming the whole medial ankle ligament complex as the tibiocalcaneonavicular ligament. This more global understanding of medial ankle ligaments has pushed forward investigations trying to repair or reconstruct this wide ligament complex as a unit, instead of treating individual components of it. Depending on the different apices of deformity present, flatfoot deformity should be addressed always with skeletal and soft tissue procedures.

CLINICS CARE POINTS

- Flatfoot deformity is explained by a combination of ligament insufficiencies. This fact explains the multiple apices of deformity generally present in flatfeet cases.[1]
- An isolated failure of the posterior tibial tendon is not enough to explain a flatfoot deformity.[4]
- An essential component of hindfoot malalignment is a coronal rotation of the talus over the calcaneus. This malrotation must be addressed when treating flatfoot deformities.[3]
- The medial ankle ligament complex probably works as a functional unit, with insertion points on the tibia, navicular, and calcaneus. It is called the tibiocalcaneonavicular ligament, comprising the previously named tibionavicular, tibiospring, and tibiocalcaneal ligaments.[18]
- Recent studies try to reconstruct the tibiocalcaneonavicular ligament as a complex, not as individual units.[35]

DISCLOSURE

The authors have nothing to disclose. Q14

REFERENCES

1. Deland JT, de Asla RJ, Sung IH, et al. Posterior tibial tendon insufficiency: which ligaments are involved? Foot Ankle Int 2005;26(6):427–35.
2. Deland JT. Adult-acquired flatfoot deformity. J Am Acad Orthop Surg 2008;16(7): 399–406.
3. Kodithuwakku Arachchige SNK, Chander H, Knight A. Flatfeet: biomechanical implications, assessment, and management. Foot (Edinb) 2019;38:81–5.
4. Cifuentes-De la Portilla C, Larrainzar-Garijo R, Bayod J. Biomechanical stress analysis of the main soft tissues associated with the development of adult acquired flatfoot deformity. Clin Biomech (Bristol, Avon) 2019;61:163–71.

5. Watanabe K, Kitaoka HB, Fujii T, et al. Posterior tibial tendon dysfunction and flatfoot: analysis with simulated walking. Gait Posture 2013;37(2):264–8.
6. Arangio GA, Salathe EP. A biomechanical analysis of posterior tibial tendon dysfunction, medial displacement calcaneal osteotomy and flexor digitorum longus transfer in adult acquired flat foot. Clin Biomech (Bristol, Avon) 2009;24(4): 385–90 [published correction appears in Clin Biomech (Bristol, Avon). 2009 Jul;24(6):530].
7. Swanton E, Fisher L, Fisher A, et al. An anatomic study of the naviculocuneiform ligament and its possible role maintaining the medial longitudinal arch. Foot Ankle Int 2019;40(3):352–5.
8. Chan F, Bowlby MA, Christensen JC. Medial column biomechanics: nonsurgical and surgical implications. Clin Podiatr Med Surg 2020;37(1):39–51.
9. Kadakia AR, Kelikian AS, Barbosa M, et al. Did failure occur because of medial column instability that was not recognized, or did it develop after surgery? Foot Ankle Clin 2017;22(3):545–62.
10. Saltzman C, El-Khoury G. The hindfoot alignment view. Foot Ankle Int 1995; 16:572.
11. Paley D, Herzenberg J, Tetsworth K, et al. Deformity planning for frontal and sagittal plane corrective osteotomies. Orthop Clin North Am 1994;25(3):425–65.
12. Lopez M, Wagner P. Analisis y plan quirúrgico de deformidades en tobillo y retropié del adulto. Rev Chil Ortop Traumatol 2019. https://doi.org/10.1055/s-0039-3400508.
13. Hintermann B, Knupp M, Barg A. Joint-preserving surgery of asymmetric ankle osteoarthritis with peritalar instability. Foot Ankle Clin 2013;18(3):503–16.
14. Hintermann B, Knupp M, Barg A. Peritalar instability. Foot Ankle Int 2012;33(5): 450–4.
15. Nosewicz TL, Knupp M, Bolliger L, et al. Radiological morphology of peritalar instability in varus and valgus tilted ankles. Foot Ankle Int 2014;35(5):453–62.
16. Wang B, Saltzman CL, Chalayon O, et al. Does the subtalar joint compensate for ankle malalignment in end-stage ankle arthritis? Clin Orthop Relat Res 2015; 473(1):318–25.
17. Williamson ER, Chan JY, Burket JC, et al. New radiographic parameter assessing hindfoot alignment in stage II adult-acquired flatfoot deformity. Foot Ankle Int 2015;36(4):417–23.
18. Cromeens BP, Kirchhoff CA, Patterson RM, et al. An attachment-based description of the medial collateral and spring ligament complexes. Foot Ankle Int 2015; 36(6):710–21.
19. Masaragian HJ, Massetti S, Perin F, et al. Flatfoot deformity due to isolated spring ligament injury. J Foot Ankle Surg 2020;59(3):469–78.
20. Hintermann B. Medial ankle instability. Foot Ankle Clin 2003;8(4):723–38.
21. Kitaoka HB, Patzer GL. Subtalar arthrodesis for posterior tibial tendon dysfunction and pes planus. Clin Orthop Relat Res 1997;345:187–94.
22. Kitaoka HB, Luo ZP, An KN. Subtalar arthrodesis versus flexor digitorum longus tendon transfer for severe flatfoot deformity: an in vitro biomechanical analysis. Foot Ankle Int 1997;18(11):710–5.
23. Cohen BE, Johnson JE. Subtalar arthrodesis for treatment of posterior tibial tendon insufficiency. Foot Ankle Clin 2001;6(1):121–8.
24. Knupp M. The use of osteotomies in the treatment of asymmetric ankle joint arthritis. Foot Ankle Int 2017;38(2):220–9.
25. Vander Griend R. Lateral column lengthening using a “Z” osteotomy of the calcaneus. Tech Foot Ankle Surg 2008;7(4):257–63.

26. Conti MS, Garfinkel JH, Ellis SJ. Outcomes of reconstruction of the flexible adult-acquired flatfoot deformity. Orthop Clin North Am 2020;51(1):109–20.
27. Chan JY, Greenfield ST, Soukup DS, et al. Contribution of lateral column lengthening to correction of forefoot abduction in stage IIb adult acquired flatfoot deformity reconstruction. Foot Ankle Int 2015;36(12):1400–11.
28. Patel M, Barbosa M, Kadakia A. Role of spring and deltoid ligament reconstruction for adult acquired flatfoot deformity. Tech Foot Ankle 2017;16:124–35.
29. Huang CK, Kitaoka HB, An KN, et al. Biomechanical evaluation of longitudinal arch stability. Foot Ankle 1993;14(6):353–7.
30. Williams BR, Ellis SJ, Deyer TW, et al. Reconstruction of the spring ligament using a peroneus longus autograft tendon transfer. Foot Ankle Int 2010;31(7):567–77.
31. Xu C, Zhang MY, Lei GH, et al. Biomechanical evaluation of tenodesis reconstruction in ankle with deltoid ligament deficiency: a finite element analysis. Knee Surg Sports Traumatol Arthrosc 2012;20(9):1854–62.
32. Baxter JR, LaMothe JM, Walls RJ, et al. Reconstruction of the medial talonavicular joint in simulated flatfoot deformity. Foot Ankle Int 2015;36(4):424–9.
33. Grunfeld R, Oh I, Flemister S, et al. Reconstruction of the deltoid-spring ligament. Tech Foot Ankle Surg 2016;15(1):39–46.
34. Nery C, Lemos AVKC, Raduan F, et al. Combined spring and deltoid ligament repair in adult-acquired flatfoot. Foot Ankle Int 2018;39(8):903–7.
35. Brodell JD Jr, MacDonald A, Perkins JA, et al. Deltoid-spring ligament reconstruction in adult acquired flatfoot deformity with medial peritalar instability. Foot Ankle Int 2019;40(7):753–61.
36. Cifuentes-De la Portilla C, Pasapula C, Larrainzar-Garijo R, et al. Finite element analysis of secondary effect of midfoot fusions on the spring ligament in the management of adult acquired flatfoot [published online ahead of print, 2020 May 6]. Clin Biomech (Bristol, Avon) 2020;76:105018.
37. Kunas GC, Do HT, Aiyer A, et al. Contribution of medial cuneiform osteotomy to correction of longitudinal arch collapse in stage IIb adult-acquired flatfoot deformity. Foot Ankle Int 2018;39(8):885–93.

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