Role of Spring and Deltoid Ligament Reconstruction for Adult Acquired Flatfoot Deformity

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Abstract: Failure of the spring ligament is a known pathologic process in the setting of adult acquired flatfoot deformity (AAFD). Many surgical techniques have been described to correct the deformity associated with adult acquired flatfoot deformity; however, there are limited techniques available to reconstruct the spring ligament. The goal of spring ligament reconstruction is to restore the primary ligamentous stabilizer of the talonavicular joint and restore the stability of the hindfoot without creating secondary deformity and hindfoot rigidity. Stage IV flatfoot deformity may result in ankle valgus that places asymmetric stress on the tibiotalar joint that is ideally treated with a secondary reconstruction to avoid ankle arthrodesis or arthroplasty. Despite involving the tibiospring and deep deltoid in the Deltoid reconstruction, restoration of the normal tibiotalar relationship has proven difficult, particularly in the setting of hindfoot arthrodesis, where increased stress on the medial collateral ligament complex worsens the deformity. Spring ligament reconstruction is an evolving technique and we describe a reproducible technique with promising early clinical results.

Level of Evidence: Diagnostic Level IV. See Instructions for Authors for a complete description of levels of evidence.

Key Words: spring ligament, posterior tibial tendon dysfunction, calcaneonavicular ligament, flatfoot

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HISTORICAL PERSPECTIVE

Posterior tibial tendon dysfunction (PTTD) can result in significant morbidity with regard to function and pain for many individuals. Although a complex deformity that can involve tendinosis of the posterior tibialis tendon (PTT), contracture of gastrocnemius complex, instability of the tarsometatarsal (TMT) joints, congenitally short lateral column, the condition universally involves insufficiency of the static medial column ligamentous complex. Attenuation or frank failure of the spring ligament complex leads to collapse of the medial longitudinal arch. Although controversial as to whether failure of the spring ligament is the primary or secondary pathologic process, the compromised function of the ligament in patients with deformity is well recognized.

The PTT is a dynamic stabilizer of the hindfoot and maintains the medial longitudinal arch and offloads stress from the surrounding static osseo-ligamentous stabilizers. The tendon has a long moment arm in relation to subtalar joint, which gives it a greater advantage over other hindfoot inverters in resisting collapse of medial longitudinal arch.[1] PTT also provides greater support of the medial longitudinal arch than the flexor digitorum longus (FDL), flexor hallucis longus (FHL), and peroneus longus (PL).[2]

Primary static stabilizers of the medial hindfoot are the spring, deltoid, plantar aponeurosis. The spring ligament is described to have 3 distinct components. These components are the superomedial, inferior, and calcaneonavicular ligament. The superomedial portion originates from the anterior aspect of sustentaculum tali and inserts onto the superior and medial aspects of the navicular. The inferomedial portion originates between anterior and middle facet of the calcaneus and inserts onto the inferior aspect of the navicular.[3] The third portion originates between anterior and middle facet of the calcaneus and inserts onto the navicular tuberosity.[4] This ligamentous complex provides a sling support for the talar head and stabilizes the talonavicular joint and is contiguous with the superficial deltoid ligament.[5–7] Deland has confirmed that the spring ligament is torn or attenuated in late stages of PTTD.[8] With an attenuated spring ligament, the talus is able to plantar flex and adduct, which results in abduction of forefoot relative to the talus.[9]

Late stages of PTTD can lead to debilitating deformity with deltoid ligament involvement. The deltoid ligament complex has a superficial and deep layer, which are formed by multiple fascicles. The superficial layer originates from anterior colliculus and is composed of tibiotalar, tibiospring, tibionavicular, and tibiocalcaneal fascicles. The deep layer originates from the posterior colliculus and is composed of deep anterior and deep posterior tibiotalar fascicles.[3] The deep deltoid restrains the talus against valgus tilt and rotational forces within the ankle mortise.[5–6]

A combination of attenuation of the static stabilizers and disease of the PTT results in talonavicular deformity and collapse of medial longitudinal arch, hindfoot valgus, and forefoot abduction resulting in an apropulsive gait.[8,10–13] In a cadaveric study, isolated release of PTT in a normal foot initially did not lead to flattening of arch under cyclic gait loading secondary to intact static stabilizers. However, once these stabilizers became attenuated, a flatfoot deformity was produced that was unable to be corrected by isolated reconstruction of the PTT.[14] This is one of the primary reasons why the authors feel that the spring ligament should be addressed when surgically addressing this deformity. Spring ligament reconstruction is indicated only for patients who have a flexible deformity of the hindfoot without arthritis. Once a rigid or arthritic hindfoot deformity is present, a triple arthrodesis or medial triple (TN and ST) arthrodesis is required. In late stages of PTTD, the deltoid ligament may attenuate resulting in talar

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valgus tilt deformity. Additional deformity of the ankle, ankle valgus either with or without arthritis is known as stage IV adult acquired flat foot deformity.[15]

Extensive amount of research has been performed in the last 3 decades to understand the pathophysiology and treatment techniques. Multiple techniques have been utilized to reconstruct the spring ligament.[6,10,12,16–19] and deltoid ligament[5,20–27] along with bony realignment. Only 1 study to date has reconstructed spring and deltoid ligament simultaneously.[28] There is no data to definitively demonstrate that reconstruction of the spring/deltoid ligament complex is associated with superior outcomes. However, given the recent trend to minimizing the amount of correction obtained by a lateral column lengthening to minimize the risk of an overly rigid hindfoot that has been associated with poor functional outcomes,[29] there is a trend to obtaining correction with a more anatomic restoration of the medial column. The goal of the article is to discuss and the technique with early clinical results of the senior author.

INDICATIONS/CONTRAINDICATIONS

Patients who have failed conservative treatment will require surgical intervention if symptoms are interfering with activities of daily living. There is no specific contraindication to spring ligament and/or Deltoid reconstruction if the patient is an appropriate candidate for surgical correction of their flatfoot deformity. A fundamental requirement for soft tissue correction is the ability to passively correct the hindfoot deformity. Contraindications to joint preservation of the hindfoot include radiographic arthritis, rigid deformity or deformity, which is semirigid (cannot be corrected to neutral) should be treated with an arthrodesis. In addition, in some patients, who have severe subluxation of the talonavicular or subtalar joints may not have any remaining ligamentous stability and may require selected arthrodesis to achieve stability. In those cases of subluxation, soft tissue correction with osteotomy is unlikely to achieve hindfoot stability. In the setting of tibiotalar osteoarthritis, the deformity will not be fully corrected passively and consideration for concomitant or staged ankle arthroplasty should be given if joint preservation is ideal for the patient. In some instances, bone loss or significant articular narrowing will be appreciated on lateral distal tibia, in which case ligament reconstruction of the spring/deltoid will likely fail. In these cases, reconstruction of the hindfoot should proceed without spring/deltoid ligament reconstruction as the ligament will ultimately stretch and fail as the tibia and talus must be in apposition. If arthroplasty is required, reconstruction of the medial ligamentous complex can be considered at that time. Obese patients (body mass index > 30) may place significant stress on any soft tissue reconstruction and may be more appropriate for an isolated subtalar arthrodesis despite having a nonarthritic flexible deformity. This decision must be individualized for each patient based on their functional demands and whether the weight is secondary to increased muscle mass versus adipose.

Given the variability in the deformity that presents with stage 2 PTTD, the authors have an algorithm upon which they determine the need for medial complex reconstruction in addition to when a concomitant lateral column lengthening may be required. Spring ligament augmentation and repair with the Internal Brace (Arthex, Naples, FL) is considered when <30% uncovering of the talus is present. Talar uncovering >30% is treated with an allograft reconstruction that will be detailed below to provide a more robust repair with new tissue. In the setting of >50% uncovering or a congenital flatfoot that has become symptomatic, a lateral column lengthening is added as the authors have noted that the medial ligament reconstruction in isolation is insufficient in this case. Given the significant rigidity imparted to the hindfoot following a triple arthrodesis and the known risk of late ankle valgus, we attempt to correct a flexible deformity with extra-articular correction if possible, despite significant abduction.

PREOPERATIVE PLANNING

Preoperative planning begins with detailed medical history and physical examination. History typically includes medial sided ankle pain and swelling in the early stages of deformity with associated difficulty with running/impact exercise. In the later stages, patients may have lateral sided ankle pain from subfibular impingement or subtalar arthritis, in addition to pain at the medial talar head secondary to deformity and difficulty with activities of daily living. Physical examination should be focused on gait, standing alignment of the ankle and foot, ankle ligamentous stability testing, single leg heel raise, equinus contracture, and flexibility of hindfoot and midfoot deformity. Patients with a rigid deformity are not a candidate for joint preservation surgery. When viewed from front, collapse of medial longitudinal arch and abduction of the forefoot is appreciated. When viewed from the back, hindfoot alignment is in valgus along with "too-many-toes sign" is present. Gait will be antalgic and apropulsive with failure of hindfoot inversion at toe off. The patient will have significant difficulty (early stages) or inability (late stage) to perform a single leg heel raise on the involved extremity. Observe for residual forefoot supination if hindfoot deformity is able to be passively corrected. Equinus contracture is assessed with Silfverskiold test. A thorough neurovascular examination along with muscle strength testing is also important as rare cases of muscular imbalance may lead to a flatfoot deformity.

Radiographs of the foot and ankle including weight-bearing anteroposterior (AP), lateral, oblique views of the affected foot. Weight-bearing AP, lateral, mortise view of affected ankle along with hindfoot alignment view should also be obtained. Deformity will vary on radiographs depending on how much patient weight bears onto the affected extremity and allows the arch to collapse when obtaining radiographs, therefore the patient should be made aware that full weight-bearing is critical. Measurement of talus to first metatarsal angle both on AP and lateral foot x-rays will aid in determining the magnitude of the deformity. Multiple measurements have been described to analyze a flatfoot deformity; however, there is no algorithm that is available to guide the surgeon based on these measurements. The relevant sites of medial column collapse, whether talonavicular, naviculocuneiform (NC), or 1st TMT joints may be noted on the lateral radiograph (Fig. 1). The most relevant AP measurement, seems to be the amount of talar head uncovering and can help guide the surgeon when determine the need for a lateral column lengthening (Fig. 2). Ankle mortise view should be evaluated carefully for any mortise asymmetry. Any valgus talar tilt indicates deltoid insufficiency and needs to be addressed at the time of surgery, unless significant lateral tibial plafond erosion or ankle arthritis in noted (Fig. 3). As discussed above, in those cases, medial soft tissue reconstruction should be performed at the time of ankle arthroplasty. Hindfoot alignment view is helpful in identifying amount of hindfoot valgus.

Magnetic resonance imaging is not necessary to diagnosis PTTD, but it can add further information including the presence of subtle hindfoot arthritis that may alter the decision

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FIGURE 1. Lateral weight-bearing radiographs of 2 patients. Note that the collapse is focused at the TN joint (arrow) in (A), while there is clear focus of collapse at the naviculocuneiform joint (arrowhead) in (B).

making to an arthrodesis. There is some recent discussion that a magnetic resonance imaging of the leg can help to elucidate the quality of the muscle of the posterior tibial tendon. In the cases of healthy muscle without significant fatty atrophy, allograft reconstruction can be considered.

TECHNIQUE

Given the multiple procedures that are required to treat a flatfoot deformity, we prefer a supine position that allows access to both the medial and lateral aspects of the foot and ankle without requiring repositioning. The heel is placed at the edge of the table to facilitate obtaining fluoroscopic imaging, primarily an axial and anteroposterior image of the foot. A bump under the ipsilateral hip or a surgical bean bag positioner is utilized to internally rotate the leg into neutral rotation. The operative leg is elevated higher than unaffected leg using multiple blankets or commercially available positioner to facilitate obtaining an unobstructed lateral intraoperative fluoroscopic image. The use of tourniquet is based on surgeon preference; however, we prefer not to utilize a tourniquet as we feel this minimizes postoperative pain and bleeding. The leg is prepped just proximal to the knee to allow for placement of a sterile tourniquet if needed and allow for a gastrocnemius recession.

Our Approach

Although there is no specific order that has been described when correcting a flatfoot deformity, the author prefers to address deformity in a proximal to distal manner, and perform bony correction before soft tissue reconstruction. The first step is to correct an equinus contracture first, most commonly a gastrocnemius recession is required based on the preoperative examination. Performing this release first avoids placing stress on the bony and soft tissue fixation if performed later in the case. Bony correction of the calcaneus is then performed

FIGURE 2. Anteroposterior weight-bearing radiograph of a patient with painful adult acquired flatfoot s/p an arthroereisis device placement 2 years prior. Use of the arthroereisis implant should be used with caution in the adult population, especially in patients with significant deformity. Note that the patient has between 30% and 50% of the talar head uncovered. In this situation, the authors prefer an allograft spring ligament reconstruction without the use of a concomitant lateral column lengthening.

[medial displacement calcaneal osteotomy (MDCO) w/wo lateral column lengthening, or subtalar arthrodesis]. Given that the MDCO is very effective at correcting valgus deformity of the hindfoot with a predictable healing rate, this is performed in every procedure. Lateral column lengthening is added according to the described prior algorithm. If a navicular cuneiform arthrodesis is required, the drill hole for the spring ligament within the medial navicular is drilled before fixation. The drill is left within the medial navicular during fixation to ensure that the screws do not cross the graft site. Although the graft can be placed before fixation of the fusion, this may result in graft damage with errant drill or screw placement. Spring and/or deltoid ligament reconstruction is performed once all bony correction is obtained. Any of the other soft tissue procedures including FDL to PTT transfer and/or peroneus brevis (PB) to PL tendon transfers are usually performed last. The FDL tendon is prepared before ligament reconstruction, but transferred to PTT afterwards because the spring ligament is anatomically deep to the transferred tendon.

Medial Displacement Calcaneus Osteotomy

We prefer to perform a simple medial slide calcaneal osteotomy with the primary goal of correcting the hindfoot valgus. The osteotomy is made immediately posterior to the

FIGURE 3. A patient with stage IV posterior tibial tendon dysfunction with significant ankle valgus with associated narrowing of the lateral tibial articular surface. Isolated deltoid reconstruction is insufficient in this case to maintain a neutral ankle. Ankle arthroplasty is required to rebalance the ankle and may be performed simultaneously or in a staged manner.

peroneal tendons. To verify the appropriate placement of the osteotomy, fluoroscopy may be utilized, with a freer utilized as a radio opaque marker before making incision. Dissection should be carried out carefully to prevent injuring sural nerve. Once down to bone, a k-wire may be placed to act as a guide for the oscillating saw after verification with an axial view. The author prefers the use of a 9 mm by 30 mm micro-sagittal saw to minimize the risk of over-penetration of the medial cortex and injury to the neurovascular bundle. A broad straight osteotome is used to complete the osteotomy if not completed with a saw. A lamina spreader is used to distract the osteotomy and a freer is inserted into the medial side to free up any periosteum. Approximately 10 mm of medial displacement is obtained using manual reduction maneuver (foot plantarflexed to minimize tension from the Achilles tendon). Two k-wires for are inserted perpendicular to the osteotomy preliminarily to obtain preliminary stability. Correct placement and sufficient translation is confirmed under axial Harris and lateral ankle views under fluoroscopy. The author prefers two 5.5 mm headless screws for fixation to minimize the risk of symptomatic hardware. Insertion of excessively long screws should be avoided if lateral column lengthening is planned to prevent interference at the osteotomy site.

Lateral Column Lengthening

Our criteria for lateral column lengthening are dependent on talar head articular surface coverage by navicular. This can be quantified by measuring percentage of talar head that is uncovered on a weight-bearing AP radiograph of the foot. If there is <50% talar head uncoverage, we do not perform lateral column lengthening. We are able to achieve adequate coverage with ligament reconstruction in conjunction with aggressive medial column stabilization and MDCO. If there is >50% talar head uncoverage or the patient has a congenital flatfoot, then lateral column lengthening is performed along with ligament reconstruction.

Lateral column lengthening is performed through a separate sinus tarsi incision. Incision should end at the calcaneocuboid

FIGURE 4. An interesting example of the worsening of a stage IV ankle deformity following correction with a hindfoot fusion. Preoperatively (A) the patient had mild ankle valgus with severe subluxation of the hindfoot and collapse of the medial longitudinal arch. Following good correction of the hindfoot (B) with restoration of the medial longitudinal arch, the ankle valgus has worsened. A medial column fusion and deltoid allograft ligament reconstruction (C) has failed to restore the patient to the preoperative ankle valgus.

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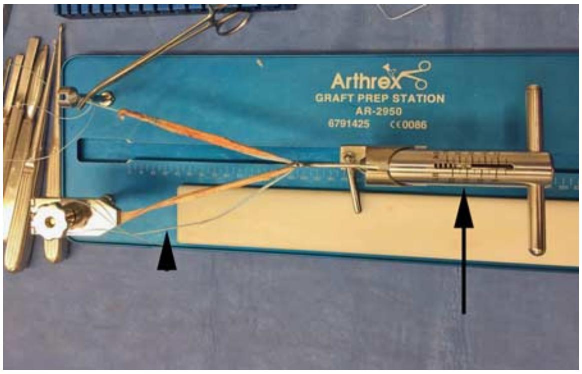

FIGURE 5. Allograft is prepared on the back table early in the case to allow for pre-tensioning. The Fibertape is sutured in parallel to the graft at the distal limb (arrowhead). The proximal limb of the graft is secured to the graft tensioner without incorporating the Fibertape to allow for tensioning at 15 lbs (arrow) for at least 20 minutes.

joint. Peroneal tendons are identified, mobilized, and protected throughout the entire procedure. Sural nerve is at danger with this approach and one should be aware of possible injury. Osteotomy for lengthening is made about 11 mm proximal to the calcaneocuboid joint between the anterior and middle facets. Our preference is to localize the osteotomy site under fluoroscopy with a K-wire, in addition to stabilizing the CC joint with an additional K-wire to prevent superior migration of the distal calcaneus. Once the cut is complete, we utilize a pin distractor to distract the osteotomy as opposed to lamina spreader to minimize compression of the bone. In addition, this allows obstruction free placement of the graft. A freer elevator is also used to free up any periosteum from the medial side. Multiple options are available with regards to graft choices, we prefer the use of a metal cage wedge construct for lengthening. The use of a cage does not come without risks and in the setting of a revision, the inability to perform an osteotomy or place a screw through the cage may impart increased difficulty to a revision procedure. In addition, in the setting of a nonunion, the entire cage must be removed, which may result in a large void than would have resulted if allograft or autograft was utilized. We prefer the cage in our practice, as the rigidity of the cage eliminates the risk of graft collapse, which is a concern when allograft or autograft is utilized. The most important aspect is to avoid over-lengthening of the osteotomy and trials are utilized to determine the appropriate graft length. The goal is to achieve improvement in the TN coverage while maintaining a supple hindfoot. Graft lengths of over 8 mm should be placed with caution as although improved radiographic correction may occur, functional limitation of motion may decrease the functional outcomes. The author prefers the use of a compression staple when utilizing a metallic cage.

Medial Column Stabilization

Our primary goal for medial column is to obtain a plantigrade 1st metatarsal that will be able to transmit forces from forefoot to the hindfoot by a stable medial column during ambulation. Options include medial cuneiform plantar flexion osteotomy (Cotton), TMT and/or NC joint arthrodesis. When performing an arthrodesis of the NC joint, we prefer to fuse the medial and middle NC joints.

Occasionally, residual forefoot supination persists after correction of hindfoot. If this is not corrected, the deformity will recur as the first metatarsal head must make contact with

FIGURE 6. Position of the navicular tunnel is identified by a lateral radiograph (A) and should be placed approximately 1 cm lateral to the navicular tuberosity (B). Intraoperative photograph of the guide pin placed through the navicular (C).

the ground with weight-bearing. Preoperative foot x-rays need to be scrutinized and correlated with a thorough physical examination to assess for TMT or NC joint osteoarthritic changes and/or instability. If there is no evidence of TMT and NC joint arthritis/instability, an isolated cotton osteotomy can be performed to plantarflex the 1st metatarsal to obtain a plantigrade foot. In presence of arthritis or instability, a TMT and/or NC joint arthrodesis should be performed and the 1st metatarsal can be plantarflexed simultaneously.

PB to PL Transfer

We reserve this tendon transfer for patients who have >30% abduction to help balance the foot. In patients with <30% abduction, we do not feel that this transfer is required to create

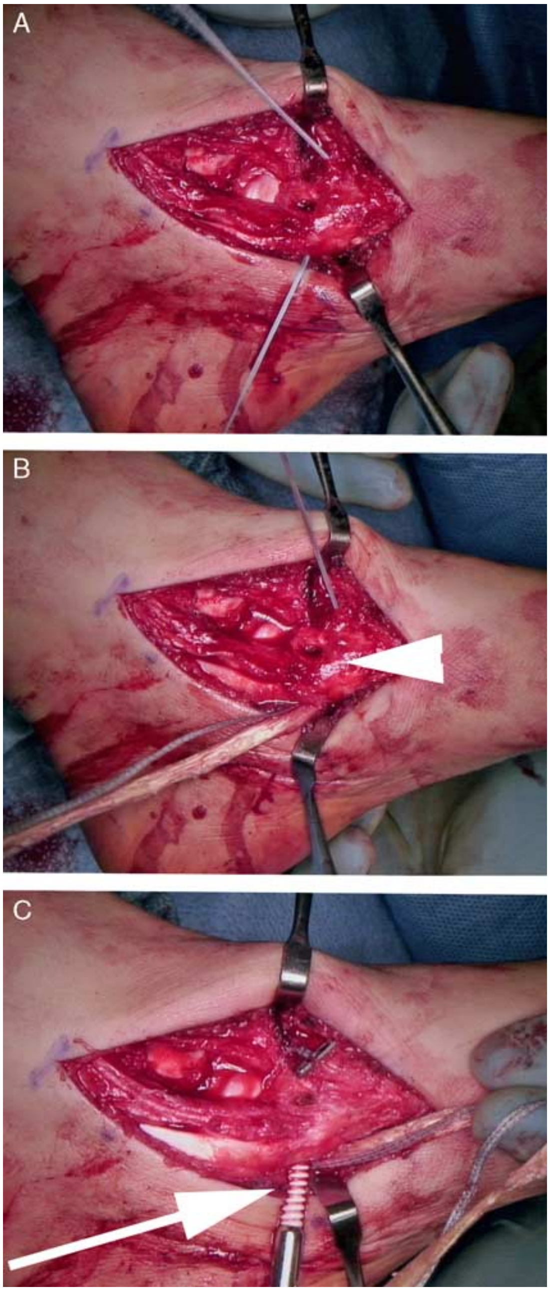

FIGURE 7. A, The leading suture of 1 end of the graft taken from plantar to dorsal. B, The graft is then pulled into the tunnel from the plantar aspect of the navicular(arrowhead). C, Following fixation of the suture button, the interference screw (arrow) is placed from the dorsal aspect to improve fixation. Following fixation, 1 free limb of suture and fibertape is available for reconstruction.

a plantigrade foot. A 2 to 3 cm incision at the posterior edge of the fibula is made approximately 5 cm proximal to the tip of the distal fibula. Peroneal tendons are visualized after incising their sheath and pulled out using an angled clamp. PB can be easily identified by having a lower muscle belly as well as being more anterior and medial at that level. If tension is placed on the longus tendon, plantar flexion of 1st metatarsal can be appreciated. Once both of the tendons are identified, they are tenodesed to each other using combination of vicryl suture and polydioxanone suture with figure of eight technique. Brevis is tenotomized just distal to the tenodesis site. This will help reduce the abduction force through the forefoot as well as improve plantarflexion of 1st metatarsal.

Spring Versus Deltoid Ligament

In the preoperative ankle radiographs, if the talus is in neutral alignment, a spring ligament reconstruction in isolation is sufficient. A valgus talar tilt in the tibial plafond signifies a deltoid ligament insufficiency and will require a deltoid ligament reconstruction in addition to spring ligament reconstruction. In the setting of severe deformity requiring a hindfoot arthrodesis, the authors have noted that some patients will develop worsening of the ankle valgus, that is felt secondary to increased strain on the Deltoid ligament following the hindfoot fusion[30] (Fig. 4). A concomitant deep Deltoid reconstruction is felt to minimize this effect, however, despite appropriate hindfoot and midfoot correction, has not been able to prevent this complication in our experience. In the currently described technique, the superficial deltoid component (tibiocalcaneal) is not reconstructed. Failure to reconstruction this component may be one of the variable that leads to late failure despite intraoperative correction. If the patient has pre-operative ankle valgus, a combined Deltoid and Spring ligament reconstruction is performed with the goal of avoiding a hindfoot fusion if at all possible. Improvement in the alignment of the ankle is achievable; however, in the setting of lateral articular wear, the deformity will not be corrected to normal. In this setting, the patient should be informed that an ankle arthroplasty has a high likelihood of being required following correction of the hindfoot.

Graft Preparation

Our graft of choice for ligament reconstruction is semitendinosus allograft, however, if a brevis to longus tendon transfer is performed, the PB may be harvested as an autograft. The usual length is between 230 mm and 250 mm. The diameter is critical as too large a graft may fracture the navicular or medial malleolus. To prevent this complication, the graft is trimmed down a 4 mm diameter that doubles over to a 6 mm graft in most cases. Before graft preparation is started, dimensions need to be measured to ensure proper fit. This can be easily done by passing a vicryl suture through 1 end and passing it through a graft sizer. After this, fold the graft into half over a suture and pass it through a sizer to make sure it fits through a 6.0 mm sizer. We like to augment the graft with FiberTape (Arthrex, Naples, FL). The wide part of the FiberTape is laid at the beginning of the graft that was initially measured. A whipstitch is placed using FiberLoop (Arthrex) approximately 15 to 20 mm proximal to the end of the graft. Each needle pass must incorporate the FiberTape along with the graft. The suture can be locked at the distal aspect of the graft by making the final pass enter just proximal to the last throw and then exit out the tip. The graft is placed on a tensioner at 15 N without incorporating the FiberTape for at least 20 minutes to minimize postoperative creep (Fig. 5). The use of the Fibertape is utilized to add a static component to the reconstruction that minimizes stress on the graft during incorporation to minimize the risk of graft failure.

Tunnel Placement

The initial tunnel is placed within the medial aspect of the navicular. A 2.4 mm beath pin is drilled plantar to dorsal. The tunnel should be placed 1 cm lateral to medial navicular cortex

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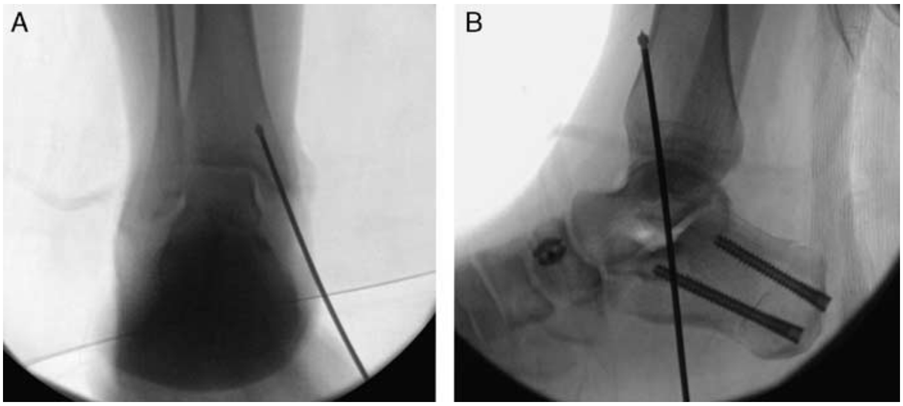

FIGURE 8. A, Fluoroscopic image depicting the spade tip placement on the AP view. Note that the guidewire is parallel to the medial cortex. The pin is directed anteriorly (B), so that it may peforate the anterior tibial cortex approximately 60 to 80 mm proximal to the tip of the medial malleolus.

to minimize fracture similar as one would place a tunnel for an FDL transfer (Fig. 6). Previously, our fixation construct included a 12 mm BicepsButton (Arthrex) on the dorsal aspect of the navicular for which a 3.2 mm guidewire was used and plantar cortex reamed with a 4.5 mm cannulated reamer. Although no failure directly attributed to the button was noted, we now use a 11 mm diameter with 4 mm collar Concave Attachable Button System Button (Arthrex) for dorsal cortex fixation. A 2.4 mm beath pin is used to obtain tunnel trajectory and bicortically reamed with a 4.5 mm cannulated reamer. We believe the latter fixation provides a wider cortical apposition dorsally and less likely to, theoretically, cutout compared with BicepsButton, which has a smaller footprint. This is especially helpful in osteoporotic bone. Sutures attached to the graft are passed from plantar to dorsal through the tunnel. Each limb of suture is passed through 1 eyelet of the button and back through the other. The other suture limb is passed in the same manner, but starting from the opposite eyelet as the first. The 2 sutures limbs are retrieved back plantarly using a suture passer. Apply tension on each suture limb to dock the graft inside the tunnel. After appropriately tensioned, a 4.75 mm Bio-Tenodesis (Arthrex) screw is inserted from plantar to dorsal direction (Fig. 7). At the end, a free needle is used to pass each limb of the excess suture through the graft and tie a knot to create a closed loop so that graft slippage will not occur.

Multiple methods have been described for tibial fixation, however, given the significant stress placed on the graft, we feel that isolated interference screw fixation was not sufficient as the medial malleolus may be osteopenic in many patients. Therefore, we utilize the ACL TightRope RT (Arthrex) system for tibial fixation. The tibial tunnel is prepared by exposing the medial malleolus. In setting of isolated spring ligament reconstruction, the Deltoid is not stripped from medial malleolus, the malleolus is approached similar to screw placement for medial malleolus fracture fixation. If the Deltoid is reconstructed simultaneously, the native ligament can be transected from the medial malleolus and imbricated with suture anchor fixation or the periosteum following completion of the graft reconstruction. A 4 mm spade tipped drill pin with an open eyelet is used to create a tunnel that begins at the tip of the medial malleolus. The pin may be directed proximal and lateral, exiting the lateral cortex. The theoretically risk to this placement is that it may result in superficial peroneal nerve injury and the graft may be disrupted if an ankle arthroplasty is required.[26] Therefore, the direction of the pin is proximal and parallels the medial cortex of the tibia exiting medial to the anterior tibial tendon. The length of the tunnel is usually between 60 and 80 mm in length to allow appropriate tensioning of the graft. This should be performed under fluoroscopy to avoid multiple passes and inadvertent widening of the tibial tunnel (Fig. 8). Given the proximity of the anterior tibial tendon to location of the tip of the pin proximally, an incision is made once the pin penetrates the anterior tibial cortex. The anterior tibial tendon is visualized and retracted laterally while the pin is advanced through the anterior cortex. A 6 mm cannulated reamer is used to ream the medial cortex under fluoroscopy while carefully avoiding perforating through the anterior cortex. The anterior cortex is essential in providing buttressing effect for TightRope RT button fixation and cannot be violated. The graft needs to be accurately measured at this point so graft is docked and tensioned inside the tibial tunnel properly as an excessively long graft will bottom out in the tunnel before achieving maximal tension. Pull the graft to the tip of the medial malleolus and mark this point on the graft with a marking pen. Make another mark 10 mm proximal to the previous mark. The graft is passed through the TightRope RT loop and folded onto itself at the more proximal mark. The graft is sutured to itself using a number 0 absorbable braided suture at the more distal mark with a figure-of-eight configuration. This is to prevent sliding of the graft when tension is applied through the tibial tunnel. If the graft slides, it will bottom out inside the tunnel and tensioning will be almost impossible. All 4 of the suture limbs from TightRope RT are placed inside the eyelet of 4 mm spade drill pin that was originally inserted. The pin is pulled manually from anterior tibia which will pull all the sutures attached the graft. Pull all the sutures proximally through the tibial tunnel to advance the button just past the anterior tibial cortex. The graft is now pulled distally to ensure button is laid flat onto anterior tibial cortex. This can be visualized directly from the anterior incision and/or can also be confirmed under fluoroscopy. The graft is tightened using the white shortening strands through the tibia. Although tightening, foot deformity correction will be easily appreciated each time the graft is tightened (Fig. 9).

If Deltoid ligament reconstruction is planned then the talar tunnel is prepared next. At this time, given that the graft within the tibia is a doubled graft, 1 free limb of the graft and the suture tape will be available for the talus. If an isolated spring ligament reconstruction is desired, the free limbs can be excised. We utilize Distal Biceps Repair Implant System

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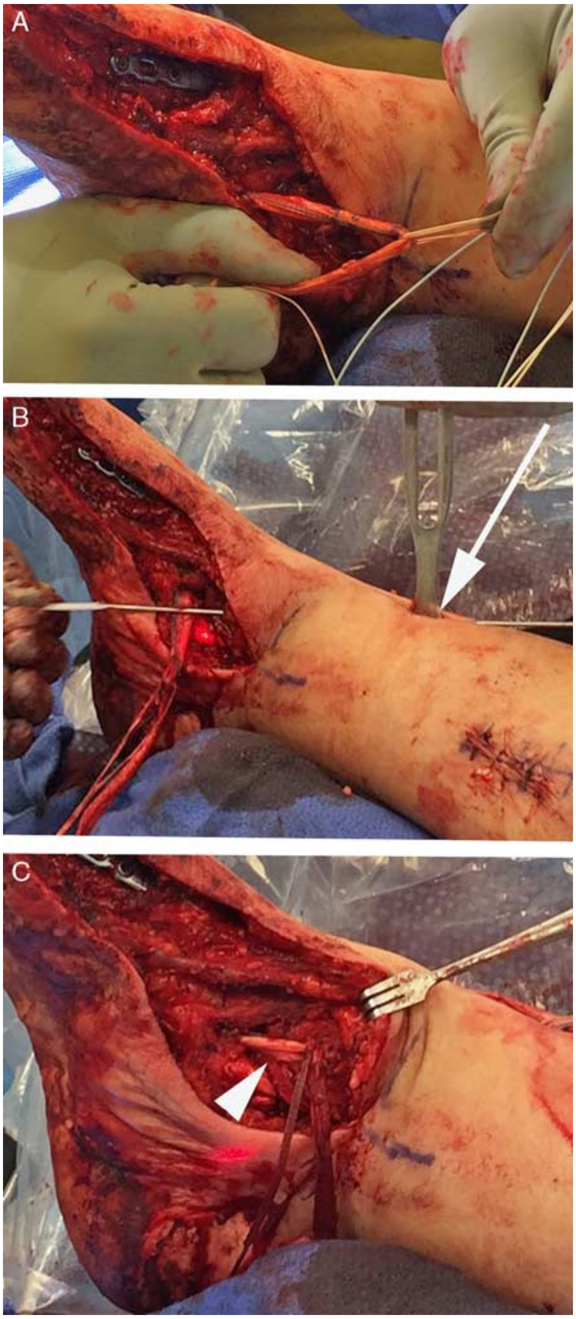

FIGURE 9. The graft is doubled over the loop (A) approximately 10 mm proximal to the entry point of the medial malleolus. A counter incision is made proximally with lateral retraction of the anterior tibialis (B). Following tightening of the graft (C) correction of the deformity will be noted.

(Arthrex) for deltoid ligament fixation into the talus. A starting point is made directly 5 mm anterior and 5 mm inferior to the tip of medial malleolus. The primary goal is to place the graft at the insertion of the deep deltoid. A 3.2 mm guidewire is drilled from this starting point to distally exiting at the talar neck laterally. The excess graft is marked 15 mm from the tip of medial malleolus and is transected. Approximately 10 mm of the graft will be docked inside the talar tunnel. The graft is prepared with a locking whipstich 10 mm proximal to the end of the graft. This end is passed through a graft sizing guide to ensure it will fit through a 4.5 mm tunnel. A 4.5 mm reamer is used to ream a unicortical tunnel from the medial talus. Each limb of suture is passed through 1 eyelet of the BicepsButton and back through the other. The other suture limb is passed in the same manner, but starting from the opposite eyelet as the first. The button inserter is placed at the end of the Biceps-Button while holding tension on all 4 strands of suture and passed through the talar tunnel onto the lateral cortex. The biceps button is then released from the inserter once passed the lateral talar cortex. Engagement of the button on the lateral talar cortex should be confirmed with fluoroscopy as soft tissue interposition will lead to loss of tension. After appropriately tensioned, a 4.75 mm Bio-Tenodesis (Arthrex) screw is inserted from medial to lateral direction. At the end, a free needle is used to pass each limb of the excess suture through the graft and tie a knot.

Final tensioning should be placed on the ACL TightRope RT shortening strands on the tibia while assistant manually inverts the foot. This will remove any slack from spring and deltoid portion of the reconstruction. A 6.25 mm Bio-Tenodesis screw can be added at the end to supplement the fixation.

If deltoid ligament is not being reconstructed then excess graft from the tibial tunnel can be transected after a 6.25 mm Bio-Tenodesis screw is used to supplement the graft fixation.

FDL Tendon Transfer

The PTT is frequently ruptured or has severe degenerative changes, however, the insertion remains intact and we use this as a stable anchor point to transfer FDL tendon. The distal stump of PTT is debrided of nonviable tissue if there is degenerative rupture, if not then it is transacted approximately 2 cm proximal to the insertion. A fish mouth cut is made in the center of the distal stump of PTT so there is dorsal and plantar half. The FDL tendon is tenotomized slightly distal to level of the PTT distal stump and placed inside the dorsal and plantar half of the PTT stump. Both of the tendons are sutured to themselves using number 0 braided absorbable suture in figure of eight technique.

In the situation where there is insufficient PTT stump, or the presence of an accessory navicular requires detachment of the insertion, graft fixation into the navicular may not be possible. In these cases, isolated use of the suture augmentation technique that has been popularized by Arthrex may be undertaken, as the suture is placed into the same tunnel as the FDL transfer. Alternatively, the medial cuneiform may be utilized for the distal fixation site for the graft, which was the senior author's original fixation point for this technique or the FDL can be placed into the medial cuneiform, with the graft placed in the navicular.

POSTOPERATIVE MANAGEMENT

In the immediate postoperative period, the patient is placed in a well-padded splint that is left in place for approximately 2 weeks. The lower extremity is elevated as much as possible to minimize swelling and pain. The patient is kept non–weight-bearing and stitches are removed at 2 weeks. To protect the soft tissue reconstruction a short leg non–weight-bearing cast is utilized from weeks 2 to 6 with continued non–weight-bearing.

At 6 weeks, lower extremity is placed in a removable controlled ankle motion walker and weight-bearing is initiated with the use an over the counter orthotic. The patient is instructed to begin with 20 lbs weight-bearing and increase as

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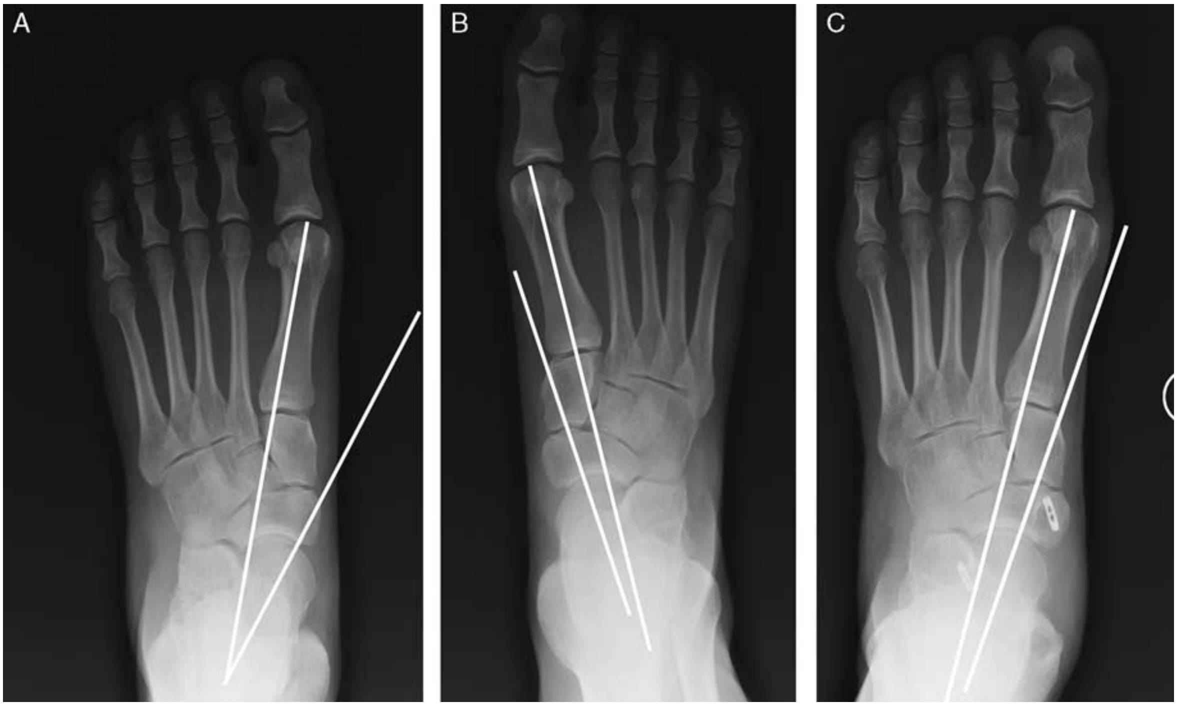

FIGURE 10. A, Preoperative weight-bearing radiograph of a 20-year-old patient with an isolated spring ligament rupture. B, Note the increase in the anteroposterior talometatarsal angle compared with the uninjured right foot. Postoperative weight-bearing radiograph at 1 year following isolated spring ligament reconstruction (C) notes improvement of the anteroposterio talometatarsal angle with near restoration to the normal right foot.

tolerated. Gentle active range of motion exercises of the foot and ankle out of the controlled ankle motion walker are encouraged.

Twelve weeks postoperative, the patient is transitioned into a lace-up ankle brace, with a full length arch support inside a gym shoe. Physical therapy for range of motion and strengthening is initiated with a focus on retraining the FDL to act as an inverter. The restriction on impact, running, barefoot walking, fashionable shoes are encouraged for a further 3 months. Six months from surgery, the patient is allowed activities as tolerated, however, most patients will never

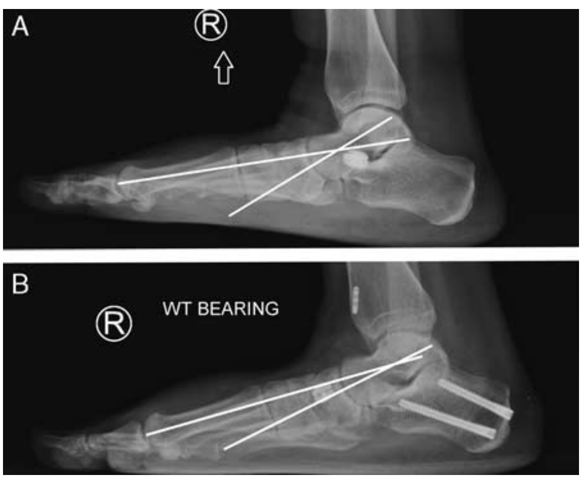

FIGURE 11. Preoperative (A) and 1-year postoperative (B) radiographs of a patient who had undergone a previous sinus tarsi implant placement. Note the improvement in Mearys angle.

achieve the ability to run or perform athletic activity at their predeformity level. Weight-bearing radiographs of ankle and foot are obtained during follow-ups at 6 weeks, 12 weeks, 6 months, and 1 year from operative date.

RESULTS

The early clinical results of the additional spring ligament reconstruction for adult acquired flatfoot have been promising. The main complicating factor when analyzing the results is that difficulty in extricating the benefit of the spring ligament reconstruction from the multiple concomitant procedures that were done; however, the correction in isolated reconstructions clearly demonstrates the effect of the procedure (Fig. 10). Although an isolated TN fusion will reliably correct the deformity, the functional loss of hindfoot motion from this procedure is significant and we feel should be avoided unless a rigid deformity or arthrosis is present. The authors have performed 17 procedures with a spring ligament reconstruction and 6 procedures with a combined spring ligament and Deltoid reconstruction. The mean preoperative Meary's angle of 26 degrees improved to 13 degrees with a mean 1-year follow-up. The talonavicular coverage improved from 43 degrees to 25 degrees postoperatively (Figs. 11–14). Of the patients who underwent spring ligament reconstruction without concomitant Deltoid reconstruction the improvement in Mearys angle was noted to be 26 degree preoperatively and 13 degrees postoperatively. Of these patients, 3 underwent lateral column lengthening for talonavicular uncovering >50%. No significant complications related to the spring ligament reconstruction were noted in these patients.

In the patients who required a Deltoid reconstruction the results are not as encouraging. The authors have noted in these complex patients, many require a hindfoot fusion to correct the

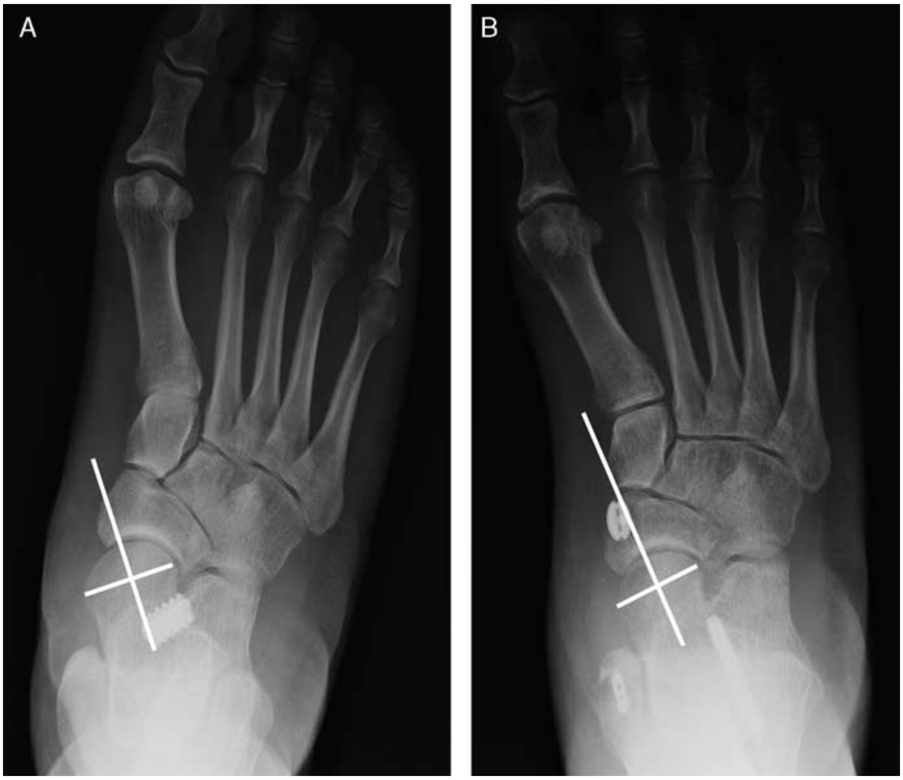

FIGURE 12. Preoperative (A) and 1-year postoperative (B) radiographs of the same patient noted in Figure 11, with improvement in the talonavicular coverage, without the need for a lateral column lengthening.

deformity and despite correction of the hindfoot, the increased stress on the Deltoid resulted in severe ankle valgus despite graft reconstruction. In patients (3) that required a hindfoot fusion with preoperative ankle valgus the deformity worsened in all cases. The preoperative valgus of 4 degrees worsened to 22 degrees. In the 3 patients who did not require a hindfoot fusion the ankle valgus the deformity the ankle valgus did not improve, however, deformity progression did not occur postoperatively with a mean of 3 degrees valgus. From our experience, despite efforts to maximize the strength of fixation, the ability to treat ankle valgus with a Deltoid reconstruction has proven difficult. We attribute this to multiple factors, including preexisting lateral plafond wear and increased stress on the reconstruction following hindfoot fusion. Failure of fixation or catastrophic failure of the graft cannot be ruled out. The authors are performing further biomechanical studies to evaluate this technique against a modification to determine if a superior reconstruction can be created. At this time, we utilize a dual reconstruction of the tibiospring and tibiotalar components of the Deltoid ligament. A 3-limb reconstruction may improve results with the third limb reconstructing the tibiocalcaneal component. However, despite improved biomechanics, the complexity of the deformity and increased strain following hindfoot reconstruction may explain why no perfect solution exists at this time.

FIGURE 13. Preoperative (A) and 1-year postoperative (B) radiographs of a more severe deformity requiring stabilization of the 1st TMT joint. Note the improvement in Mearys angle with significant correction of the plantarflexed 1st talus.

CONCLUSIONS

The surgical treatment of adult acquired flatfoot continues to evolve as we strive to improve both the radiographic and more importantly clinical outcomes. The spring ligament complex is incompetent in the setting of symptomatic adult acquired flatfoot deformity and anatomic correction of the deformity requires that the complex be reconstructed. The described technique above allows for reconstruction of the spring ligament complex that has shown efficacy in isolated ruptures

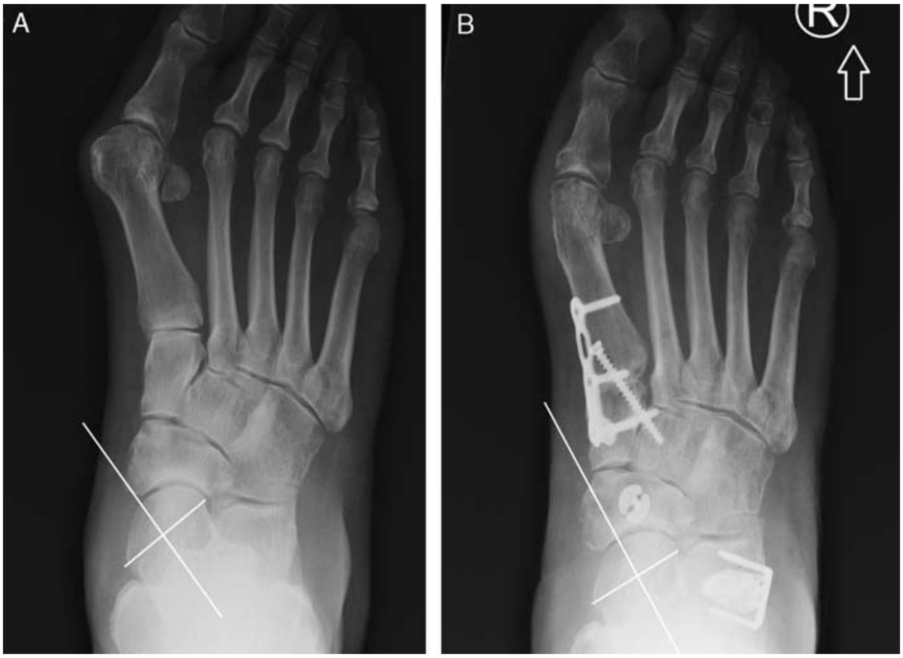

FIGURE 14. Preoperative (A) and 1-year postoperative (B) radiographs of the same patient in Figure 13, with improvement, of the talonavicular coverage. Although a more severe lateral column lengthening could have been performed, further correction would have led to hindfoot stiffness and was not performed. The use of the spring ligament reconstruction allows for improved correction of the abduction without the need to over-lengthen the lateral column.

and in cases of PTTD. We feel this method minimizes the need for a lateral column lengthening while improving the abduction and talar declination without creating hindfoot rigidity. Early results are promising, however, further research is required to determine if the functional results are superior with the addition of a spring ligament reconstruction to the multitude of other procedures required to correct the deformity. Correction of ankle valgus with a concomitant Deltoid reconstruction is difficult and results have not been as promising especially when a hindfoot fusion is required.

REFERENCES

1. Klein P, Mattys S, Rooze M. Moment arm length variations of selected muscles acting on talocrural and subtalar joints during movement: an in vitro study. *J Biomech*. 1996;29:21–30.
2. Thordarson DB, Schmotzer H, Chon J, et al. Dynamic support of the human longitudinal arch. *Clin Orthop Relat Res*. 1995;316:165–172.
3. Kelikian AS, Sarrafian S. *Sarrafian's Anatomy of the Foot and Ankle: Descriptive, Topographical, Functional*, 3rd ed. Philadelphia: Wolters Kluwer Health/Lippincott Williams & Wilkins; 2011.
4. Taniguchi A, Tanaka Y, Takakura Y, et al. Anatomy of the spring ligament. *J Bone Jt Surg-Am*. 2003;85:2174–2178.
5. Ellis SJ, Williams BR, Wagshul AD, et al. Deltoid ligament reconstruction with Peroneus Longus autograft in flatfoot deformity. *Foot Ankle Int*. 2010;31:781–789.
6. Ellis SJ, Williams BR, Yu JC, et al. Spring ligament reconstruction for advanced flatfoot deformity with the use of an Achilles allograft. *Operative Tech Orthop*. 2010;20:175–182.
7. Deland JT. Spring ligament complex and flatfoot deformity: curse or blessing? *Foot Ankle Int*. 2012;33:239–243.
8. Deland JT, de Asla RJ, Sung I-H, et al. Posterior tibial tendon insufficiency: which ligaments are involved? *Foot Ankle Int*. 2005;26:427–435.
9. Klaue K. Planovalgus and cavovarus deformity of the hind foot: a functional approach to management. *J Bone Joint Surg*. 1997;79:892–895.
10. Gazdag AR, Cracchiolo A. Rupture of the posterior tibial tendon. Evaluation of injury of the spring ligament and clinical assessment of tendon transfer and ligament repair. *J Bone Jt Surg Am*. 1997;79:675–681.
11. Orr JD, Nunley JA. Isolated spring ligament failure as a cause of adult-acquired flatfoot deformity. *Foot Ankle Int*. 2013;34:818–823.
12. Choi K, Lee S, Otis JC, et al. Anatomical reconstruction of the spring ligament using Peroneus Longus tendon graft. *Foot Ankle Int*. 2003;24:430–436.
13. Kitaoka HB, Ahn T, Luo ZP, et al. Stability of the arch of the foot. *Foot Ankle Int*. 1997;18:644–648.
14. Niki H, Ching RP, Kiser P, et al. The effect of posterior tibial tendon dysfunction on hindfoot kinematics. *Foot Ankle Int*. 2001;22:292–300.
15. Myerson MS. Adult acquired flatfoot deformity. *J Bone Jt Surg Am*. 1996;78:780–792.
16. Williams BR, Ellis SJ, Deyer TW, et al. Reconstruction of the spring ligament using a Peroneus Longus autograft tendon transfer. *Foot Ankle Int*. 2010;31:567–577.
17. Acevedo J, Vora A. Anatomical reconstruction of the spring ligament complex. *Foot Ankle Spec*. 2013;6:441–445.
18. Johnson JE, Cohen BE, DiGiovanni BF, et al. Subtalar arthrodesis with flexor digitorum longus transfer and spring ligament repair for treatment of posterior tibial tendon insufficiency. *Foot Ankle Int*. 2000;21:722–729.
19. Tan GJ, Kadakia AR, Thiele RAR, et al. Novel reconstruction of a static medial ligamentous complex in a flatfoot model. *Foot Ankle Int*. 2010;31:695–700.
20. Jeng CL, Bluman EM, Myerson MS. Minimally invasive deltoid ligament reconstruction for stage IV flatfoot deformity. *Foot Ankle Int*. 2011;32:21–30.

21. Hintermann B, Knupp M, Pagenstert GI. Deltoid ligament injuries: diagnosis and management. *Foot Ankle Clin*. 2006;11:625–637.

22. Lack W, Phisitkul P, Femino JE. Anatomic deltoid ligament repair with anchor-to-post suture reinforcement: technique tip. *IOWA Orthop J*. 2012;32:227–230.

23. Kitaoka HB, Luo Z-P, An K-N. Reconstruction operations for acquired flatfoot: biomechanical evaluation. *Foot Ankle Int*. 1998;19:203–207.

24. Hintermann B, Valderrabano V, Kundert H-P. Lengthening of the lateral column and reconstruction of the medial soft tissue for treatment of acquired flatfoot deformity associated with Insufficiency of the posterior tibial tendon. *Foot Ankle Int*. 1999;20:622–629.

25. Jacobs AM. Soft tissue procedures for the stabilization of medial arch pathology in the management of flexible flatfoot deformity. *Clin Podiatr Med Surg*. 2007;24:657–665.

26. Haddad SL, Dedhia S, Ren Y, et al. Deltoid ligament reconstruction: a novel technique with biomechanical analysis. *Foot Ankle Int*. 2010;31:639–651.

27. Williams BR, Ellis SJ, Yu JC, et al. Stage IV adult-acquired Flatfoot deformity deltoid ligament reconstruction. *Operative Tech Orthop*. 2010;20:183–189.

28. Grunfeld R, Oh I, Flemister S. Reconstruction of the deltoid-spring ligament. *Tech Foot Ankle Surg*. 2016;15:39–46.

29. Baxter JR, Demetracopoulos CA, Prado MP, et al. Lateral column lengthening corrects hindfoot valgus in a cadaveric flatfoot model. *Foot Ankle Int*. 2015;36:705–709.

30. Song SJ, Lee S, O'Malley MJ, et al. Deltoid ligament strain after correction of acquired flatfoot deformity by triple arthrodesis. *Foot Ankle Int*. 2000;21:573–577.