Managing the adult flexible flatfoot deformity. The past, present and the future: an evolution of thinking

Tratando a deformidade do pé plano flexível do adulto. O passado, o presente e o futuro: a evolução do pensamento

Mark Myerson[1], Shu Yuan Li[1]

Keywords:
Flatfoot/physiopathology; Flatfoot/surgery; Orthopedic procedures/methods; Orthopedic procedures/trends; Adult

ABSTRACT

There is a varied spectrum to the flexible flatfoot deformity. This article aims to elucidate the senior authors classification and treatment algorithm for this condition. Although there are several ways of dealing with this condition, the main aim should be to correct the three components of heel valgus, tendon/muscle imbalance and forefoot supination. We have had good results with a novel technique of reconstructing the PTT, however this is only anecdotal. Further studies delineating the outcomes of PTT allograft reconstruction need to be performed. Future research should focus on outcomes and how they relate to preoperative MRI. It also remains to be determined what the optimal tension is for these grafts.

Descritores:
Pé chato/fisiopatologia; Pé chato/cirurgia; Procedimentos ortopédicos/métodos; Procedimentos ortopédicos/tendências; Adulto

RESUMO

As deformidades que caracterizam o pé plano flexível do adulto apresentam-se em um amplo espectro de formas. Este artigo pretende elucidar a classificação e o algoritmo de tratamento para esta patologia concebidos pelo autor principal (MM). Embora haja diferentes modos de tratar esta patologia, os objetivos principais são a correção de três componentes - o valgismo do retropé, o desbalanceamento músculo tendíneo e a supinação do antepé. Os autores referem bons resultados com uma nova técnica de reconstrução do tendão tibial posterior mas ainda de forma incipiente. Sugerem que estudos mais aprofundados sobre os resultados da reconstrução do tendão tibial posterior com aloenxêrto devem ser realizados. Estes estudos devem focar nos resultados e como estes se relacionam com os achados pré-operatórios da ressonância magnética. Ainda é necessário determinar qual deve ser o tensionamento ideal para estes enxertos.

[1] The Foot and Ankle Association, Baltimore, USA.

Corresponding author:
Mark Myerson, MD
The Foot and Ankle Association Inc.
1209 Harbor Island Walk, Baltimore, MD 21230, USA.
Baltimore, Maryland
E-mail: Mark4feet@aol.com

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INTRODUCTION AND A HISTORIC PERSPECTIVE

Management of the adult flexible flatfoot deformity has changed and evolved significantly over the past 30 years, so let us begin with the concepts of treatment in the early 1980's. At that time, it was still believed that one could repair the ruptured posterior tibial tendon (PTT), whether by end-to-end suture or with a Z type shortening. While this may theoretically be possible, the problem with this approach was that it was not recognized that the rupture of the PTT represents only one of a spectrum of problems that occur with the adult acquired flatfoot deformity, and of course these attempted repairs were never going to work. Perhaps if this type of approach were used today by obtaining complete muscle and skeletal balance of the foot, it may be a treatment to consider. What is not by many surgeons today is that even in the ruptured

PTT, there are still viable collagen cells. There are some surgeons who today still believe therefore that there is a role for retaining the repaired PTT in conjunction with all the additional procedures required to correct the deformity and balance the foot.[1]

In the 1980's, quite apart from repair of the PTT, many surgeons performed a flexor digitorum longus (FDL) transfer or a tenodesis of the FDL to the ruptured posterior tibial tendon (PTT). This does not make anatomic sense, because the ruptured PTT has an excursion of 12mm, and a normal FDL tendon with an excursion of almost 2cm and it becomes very difficult to balance the force of these tendons. Why would one want to use a normal FDL and a tenodesis of tendon this to a ruptured PTT? This was however the standard treatment used in the early 1980's.[2,3]

The use of the FDL continued as a stand-alone procedure continued however in the mid 1980's, and authors believed that the use of the FDL alone would decrease pain of the ruptured tendon. So, think about the cause of pain in the PTT rupture. Why is there pain, why does it occur, and is this always in the location of the tendon tears? Regardless of what in fact are the metabolic factors that cause these pain "generators" they certainly disappeared in many patients with excision of the torn PTT and substitution with the FDL.[4] This was the continued impetus to the treatment with an isolated FDL transfer. However, this too does not make any sense. So for almost a decade from the late 1970's through the mid 1980's the use of a transfer of the FDL into the navicular with excision of the ruptured PTT was the most common procedure performed. Note that this was done in the absence of any additional procedures, such as osteotomies or limited arthrodesis.[4]

The concept of FDL transfer continued through today, but has changed over the years, and although our earlier publications indicated that the results of this treatment (combined with a calcaneus osteotomy) was satisfactory, we now recognize that a transfer of the FDL is not the ideal procedure for correction of the balance of deformity. The FDL is far weaker than the PTT and regardless of the additional procedures performed to improve the structure of the foot, the muscle imbalance remains. Therefore, we have to do something else to increase inversion power or at the least, weaken the eversion power. The peroneus brevis acts as a deforming force in the flatfoot deformity and the unopposed pull of the peroneus brevis causes eventual elongation of the medial supporting structures, eventually leading to an abduction deformity. In the absence of the PTT, the functioning peroneus brevis therefore will always contribute to the worsening of the flatfoot deformity.

These procedures ignored the forces on the hindfoot as a result of the rupture of the PTT and in the in the mid 1980's Myerson introduced the concept of adding a calcaneus osteotomy to the FDL transfer for management of the flexible flatfoot.[5] This came about quite coincidentally, when the senior author was looking for a treatment for the adolescent flatfoot and read the work of Koutsougiannis which recommended a calcaneus osteotomy for all flatfeet regardless of the underlying pathology or cause.[6] This made more anatomic sense and the medial translation osteotomy was introduced by Myerson as a routine addition to the FDL transfer. Originally described by Gleich in 1893, Koutsogiannis reintroduced the MDCO for the correction of the flatfoot deformity in 1971 and the application of this procedure to the management of the ruptured PTT was popularized by Myerson et al in the late 1980's. Since then several studies have shown the good results with this procedure.

Although this approach was an improvement in the management of the flatfoot, it was still quite inadequate because it failed to recognize the many variations of the type of flatfoot deformities. We published our long term results of this procedure in 2004 with reasonable outcomes, but began to note that in this group of patients for whom an FDL transfer and a calcaneus osteotomy was performed, many of them began to fail with recurrence of the flatfoot.[1] This was largely the result of persistence of the muscle imbalance, and the presence of deformity of the medial column which had not been routinely corrected in this group of patients.

The present treatment of the adult acquired flatfoot deformity

Nothing in foot and ankle surgery elicits controversy as much as the "appropriate" correction of the adult flexible flatfoot deformity (AFFD). To some extent, this controversy has a lot to do with the many satisfactory operations that were available for correction of similar deformities. We were misguided during the 1980's as to the pathology and the pathologic anatomy of deformity, whether flexible or rigid. As a result, we and many other surgeons chose an operation that was somewhat simplistic. For example, for the flexible flatfoot and a rupture of the posterior tibial tendon (PTT) we and other surgeons used a calcaneus osteotomy with medial translation and added a tendon transfer, usually the flexor digitorum longus (FDL) to

substitute for the torn PTT. This of course failed to recognize the variety of deformities that exist in the AFFD, in particular, the various joints on the medial side of the foot, which can sag or develop arthritis. The same applied to the various types of abduction of the forefoot or midfoot where the apex could be either at the talonavicular (TN), naviculocuneiform (NC) or tarsometatarsal (TMT) joint. Because of the plethora of these surgical alternatives, choosing a procedure was confusing. Decision-making does, of course, depend on the severity of the deformity, the appearance of the foot, and the flexibility of the hindfoot and forefoot.

Perhaps the most important aspect of decision-making is the presence of flexibility in the hindfoot. Specifically, is the subtalar joint completely correctable into a neutral position with or without supination of the forefoot? If such a reduction is possible, can it be achieved without associated significant forefoot supination? The overall approach to correction of deformity is therefore based on the flexibility of the foot; the presence of rupture of the posterior tibial tendon, the spring ligament, or the deltoid ligament; and the presence of any arthritis or secondary deformity of the midfoot. To understand this further, one must study the classification systems for the flatfoot that have been used over these past decades, since these give an indication as to what the surgical options were considered historically for each deformity.

The first attempt at a classification of the adult acquired flatfoot was by Johnson and Strom in the late 1980's.[3] This was quite simplistic, and divided the problem into three stages: Stage I was considered to be an early flatfoot associated with tenosynovitis but with minimal flatfoot deformity, and if non surgical treatment failed, they proposed a tenosynovectomy of the PTT. This however completely ignored the fact that tenosynovitis is invariably associated with a slight flatfoot and a tight gastrocnemius. Therefore, we would now routinely add a medial translational calcaneus osteotomy with or without a gastrocnemius recession to the tenosynovectomy for early stage disease. Their stage II consisted of a flexible flatfoot deformity, but the type of flexibility and the apex of the deformity was never characterized. For most of the 1980's and 1990's this type of deformity was treated with a flexor digitorum longus (FDL) transfer. Some surgeons transferred the FDL into the navicular, and some as a tenodesis to the ruptured PTT, but no recognition of the different types of midfoot and hindfoot deformity was made at this time. The addition of a medial translational calcaneus osteotomy to the FDL transfer as introduced by Myerson, became a routine part of this reconstruction for many surgeons, and although it addressed the valgus deformity of the heel, it still failed to address the imbalance of muscle forces on the hindfoot following rupture of the PTT. Stage III consisted of rigid deformity with hindfoot valgus in which the subtalar joint was not correctable to neutral, and triple arthrodesis was the treatment of choice. While the majority of rigid deformities do indeed require a triple arthrodesis, there are many additional procedures, which must also be considered as part of the spectrum of a rigid flatfoot deformity. Myerson subsequently added a Stage IV to this rudimentary classification system which included valgus deformity of the ankle associated with a rupture of the deltoid ligament.[5]

A classification system of the flatfoot is only helpful if it describes and characterizes all types of deformity, and provides a corresponding treatment alternative for every aspect of deformity. We recognized that few adult acquired flatfoot deformities could be placed into one of the four stages described above. Probably the most detailed and clinically useful system recognized is the one devised by Myerson et al. in 2007, which is described in more detail below.[7] This system describes the characteristic clinical and radiographic findings for each stage and the treatment algorithm, which should be adopted.

Stage II: PTT rupture with flexible flatfoot

This stage is characterized by a collapse of the longitudinal arch, hindfoot valgus, weakness of inversion in a plantar flexed foot and inability to perform a single heel rise test. The pathology is a weak or ruptured tendon but the hindfoot is still mobile. It is further divided into three sub-stages with the first sub-stage being further subdivided into two categories.

Stage IIA (hindfoot valgus): This stage is characterized by a flexible hindfoot valgus. Once the heel is reduced to neutral position, the forefoot supination is either minimal or completely reducible (Stage IIA 1) or fixed (Stage IIA 2). Forefoot supination occurs because the forefoot always has to remain plantigrade regardless of what is happening in the hindfoot. So, if the hindfoot moves into valgus, the forefoot has to adapt to these changes allowing the medial and lateral columns of the forefoot to remain in contact with the floor. If one reduces the heel into a neutral position, then these changes become apparent with a supination of the medial forefoot.

Stage II A-1 (Flexible forefoot varus): Once the flexible hindfoot is reduced to a neutral position, the forefoot varus that is also flexible can be corrected by plantar flexing the ankle and relaxing the contracture of the gastrocnemius.

Stage II A-2 (Fixed forefoot varus): This is differentiated from stage II A-1 by the fact that once the hindfoot deformity is corrected by manipulating the heel into neutral, the forefoot varus which is unmasked is fixed and does not correct by plantarflexing the ankle and easing the tension on the gastrocnemius.

Stage IIB (Forefoot abduction): This stage is characterized by the presence of abduction at the forefoot as the key deformity in conjunction with the above mentioned hindfoot valgus and with or without forefoot supination. The abduction of the forefoot can occur either at the tarsometatarsal joints or the Chopart joints. The latter is identified by uncoverage of the talar head.

Stage IIC (Medial ray instability): The relevant feature of this stage is medial ray instability. On correcting the hindfoot to a neutral position, the forefoot varus is not corrected even on attempted forced passive plantarflexion. This is due to an unstable medial column, since the first ray tends to dorsiflex with the heel being corrected, causing the foot to pronate on weight bearing and leading to subtalar impingement and pain. The instability can occur anywhere along the length of the medial column i.e. the first TMT joint, naviculocuneiform joint, talonavicular joint or a combination of these.

Once we have established that the hindfoot is correctible, focus should be then paid to what is occurring at the forefoot. This is done by holding the heel and bringing it into a neutral position and then assessing the whether the forefoot is supinated or not. If it is supinated, then the ankle is plantar flexed to determine whether the forefoot supination corrects itself. This occurs because the gastrocnemius complex is relaxed on plantarflexion and this corrects the deformity (Figure 1).

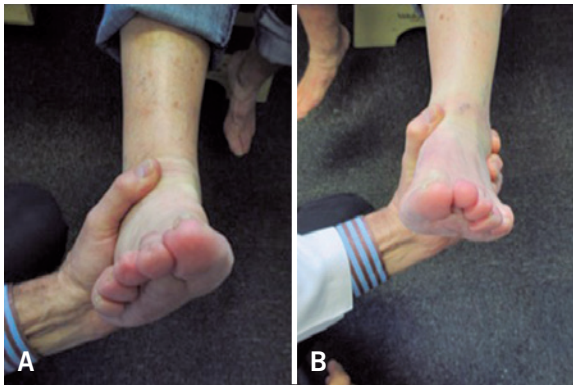

Figure 1. Examination of forefoot varus: A: heel clasped behind uncorrected hindfoot, which is in valgus; B: Note the forefoot varus after the hindfoot has been corrected to neutral. This forefoot deformity may then be flexible (corrects with ankle plantar flexion) or fixed (remains uncorrected with ankle plantarflexion)

Operative management

The key to treatment of a flexible flatfoot deformity should aim to correct the essential components of the problem:

- the hindfoot valgus
- the tendon/muscle imbalance
- forefoot supination.
- forefoot abduction
- the gastrocnemius contracture

Surgical management of the flexible flatfoot has undergone a vast change with joint preserving procedures being used more frequently as opposed to arthrodesis which was used in the past. We look at some of these interventions listed below. Note that for all of these procedures, one has to determine if a gastrocnemius contracture is present, and this must be addressed surgically with a gastrocnemius recession. The technique for a gastrocnemius recession will not be discussed in this paper.

Correcting the hindfoot valgus deformity

There are only three procedures which will correct hindfoot valgus deformity: a medial displacement calcaneal osteotomy (MDCO), a subtalar arthroereisis procedure, or a subtalar arthrodesis. It should be noted however that we do not use a subtalar arthroereisis as part of the management of the hindfoot valgus deformity in the adult. While this is a very useful surgical procedure for correction of the child's foot, our results of treatment in the adult have been poor, complicated by a high rate of pain and subtalar arthritis. If there is really significant flexible hindfoot valgus, a subtalar arthrodesis is a useful procedure to correct deformity, particularly in the obese patient for whom a standard correction may not be sufficient. This is clearly a departure from the concept of maintaining flexibility of the hindfoot in a Stage II rupture, but this is a procedure which we use for patients where there is a concern that the deformity will recur despite correct adherence to the steps of correction (Figure 2).

Figure 2. The pre and postoperative radiographs of an obese female patient with a rupture of the PTT and a rupture of the spring ligament. This was treated with a subtalar arthrodesis, transfer of the FDL, and a spring ligament reconstruction

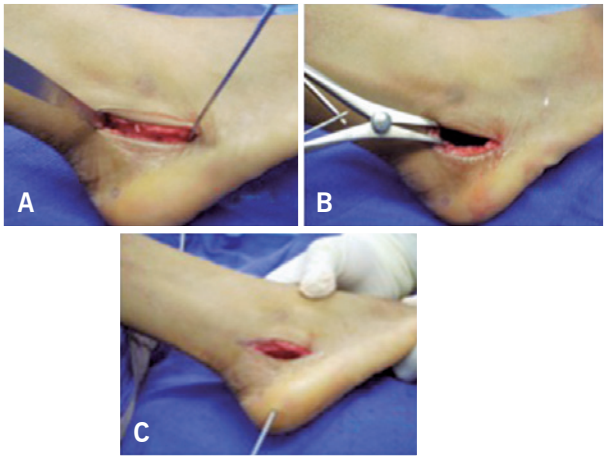

Figure 3. Calcaneal osteotomy. The skin is retracted (A), the osteotomy performed and opened with a laminar spreader (B) and a guide pin inserted for a cannulated screw or a specific calcaneus medial displacement plate following 10mm of medial displacement (C)

The MDCO is the mainstay of correcting the hindfoot valgus, and is either performed alone, or in conjunction with a lengthening of the lateral column of the calcaneus, and aims to change the calcaneal axis and hindfoot alignment. This in turn helps protect the soft tissue reconstruction by taking the tension off the tendon transfer or the reconstruction. It also realigns the pull of the Achilles tendon and the moment arm of the gastrocnemius soleus complex is converted from an everter to an inverter of the hindfoot with medial translation of the calcaneus.

We perform the MDCO osteotomy through a lateral oblique incision, one centimeter below the tip of the fibula in line with the osteotomy. A full thickness flap is developed with subperiosteal dissection down to bone. Care is taken to protect the branches of the sural nerve, although we warn patients that numbness is frequent post operatively. Retractors are placed on the plantar and dorsal aspects of the calcaneus for soft tissue protection and a self-retaining retractor is also used to stretch the margins of the incision and maintain exposure during the osteotomy. An oscillating fan saw blade is used at right angle to the lateral calcaneal wall to perform the osteotomy. The medial wall of the calcaneus is carefully perforated with a slight punching action of the saw to prevent inadvertent soft tissue damage medially. After distraction of the osteotomy with a laminar spreader, a displacement of 10 to 12mm can be performed medially and fixation with either a cannulated screw or a locking plate can be performed (Figure 3).

Managing the muscle imbalance

This is the key to the success of the procedure and many changes have taken place in my own approach to the problem over the decades. With rupture of the PTT, there is always muscle imbalance due to weakness of inversion, and unbalanced activity of the peroneal musculature, which of course produces increasing eversion. The PTT is the principle supinator of the subtalar joint along with functioning as an adductor of the midfoot and plantar flexor of the ankle. So if this tendon is ruptured, we have to replace it with something else to balance the muscle forces of the hindfoot, but in doing so we should consider the strength of the transferred muscle. The FDL has only 28% strength of the PTT and the FHL has 50% strength of the PTT. Although some surgeons have advocated transfer of the FHL instead of the FDL to replace the torn PTT, 100% of patients report loss of FHL strength and we believe this is not an acceptable outcome. However, transfer of the FDL alone is also not adequate and the medial shift of the calcaneus with the MDCO does not ever compensate for this imbalance.

Although our earlier publications indicated that the results of this combination of treatment *i.e.* FDL transfer with MDCO was satisfactory, we now recognize that a transfer of the FDL is not the ideal procedure for correction of the balance of deformity. The FDL is far weaker than the PTT, and regardless of the additional procedures performed to improve the structure of the foot, the muscle imbalance remains. We also noted many patients slowly developing a recurrent flatfoot deformity, and while many of these were not symptomatic, given the deformity, we believed that sooner or later symptoms would recur. Therefore we have to do something else to increase inversion power, or to consider weakening the eversion power. The peroneus brevis acts as a deforming force

in the flatfoot deformity and the unopposed pull of the peroneus brevis causes eventual elongation of the medial supporting structures, eventually leading to an abduction deformity. In the absence of a functioning PTT, the peroneus brevis therefore will always contribute to the worsening of the flatfoot deformity. Therefore we now recommend a transfer of the peroneus brevis tendon to the peroneus longus in conjunction with the FDL transfer, and the calcaneus osteotomy. By virtue of the insertion of the peroneus longus on the base of the 1st metatarsocuneiform joint the tendon transfer helps to strengthen the first metatarsal plantarflexion and reduces slightly the eversion of the hindfoot thereby improving the deformity correction. This can be performed through the same incision used for the calcaneal osteotomy by extending it slightly proximally and distally.

Flexor digitorum longus (FDL) transfer surgical technique

A medial incision over the PTT is made and the tendon inspected to determine if just a debridement will be sufficient or whether an FDL transfer or tendon graft procedure is indicated, depending on the disease staging. It is not always easy to see the rupture of the PTT tendon, but by rotating the tendon the tear is seen since it is usually on the posterior surface of the tendon (Figure 4).

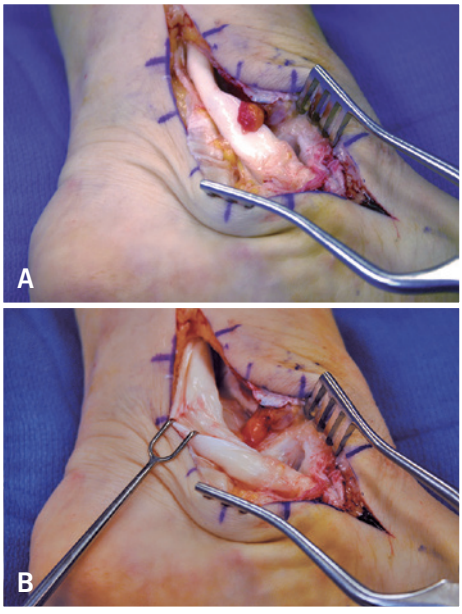

Figure 4. Note the tenosynovitis and the tearing and narrowing of the PTT (A). The rupture of the tendon is frequently visible on the posterior surface when rotating the tendon (B)

We transfer the FDL to the navicular by drilling through the bone with a 4.5mm drill and passing the tendon through the intraosseous tunnel from plantar to dorsal. The tendon is then tensioned and sutured onto the periosteum both on the superior and undersurface of the navicular. It is not necessary to use an interference screw, and this suture repair allows immediate weight bearing without concern for stretching. The tension that is set on the tendon during suture is important. The tendon must be tight, and although there are different opinions as to just how tight this transfer should be, my preference is to tighten the tendon slightly to produce very slight inversion of the foot. This should be half way between maximum tension and maximum relaxation. Some surgeons place the tendon tension at maximum but this cannot possibly be the correct tension to apply to any tendon transfer.

Managing the spring ligament tear

The function of the spring ligament is to maintain the position of the talar head, forming the medial plantar sector of the articular cavity known as "*acetabulum pedis*". The spring (calcaneo navicular) ligament, the deltoid ligament, the plantar ligaments and the plantar fascia in a passive way with the posterior tibial tendon in an active way, function to stabilize the subtalar joint and the medial longitudinal arch. It is essential that one always inspect the spring ligament complex during repair and reconstruction of the ruptured PTT. Furthermore, injury of the spring ligament can occur in isolation not associated with a tear of the PTT. While this isolated injury of the spring ligament is not common it does occur, and we have frequently made the error of assuming that a rupture of the PTT is present when it is the torn spring ligament that produces the exact same deformity of the hindfoot. The clinical diagnosis of this isolated tear is not easy, because the patient will have pain at the insertion of the PTT, but normal power and strength of the PTT is present. Eventually, rupture of the spring ligament will lead to a more vertically oriented talus.

Historically, we attempted repair of the spring ligament with sutures, but these are rarely strong enough to support the repair. An alternative treatment is to place one suture anchor into the navicular and another into the sustentaculum tali and then use the sutures from the anchors to reinforce the repair of the ligament. As an alternative, we occasionally use a tendon graft which passes from the sustentaculum tali through a tunnel under the plantar medial head of the navicular to support the head of the talus. A 4.5mm drill hole is made over a cannulated guide pin which is inserted 1cm under the

sustentaculum. A lateral radiograph must be obtained to verify that it is not too close to the subtalar joint or the edge of the sustentaculum which can cause fracture. The 4.5mm drill hole is then made and the allograft tendon is inserted into the hole with an interference screw or suture anchor holding the position securely. The second hole is made from the plantar medial inferior pole of the navicular aiming dorsally out the center of the navicular. The tendon is then pulled through and an interference screw is inserted under the navicular to maintain maximum tension (Figure 5). The tension is

Figure 5. The FDL is visualized passing from inferior to superiorly through the bony tunnel created in the navicular. It is sutured to the stump of the PTT and then dorsally to the periosteum over the navicular

set with the foot in slight varus at the talonavicular joint. If this procedure is performed in conjunction with an FDL transfer then one has to be careful with the drill tunnels in the navicular to prevent fracture. There are times when the spring ligament is stretched out, but the pathology of the capsuloligamentous pathology extends to the deltoid ligament as well. In these cases, the reconstruction is performed using a graft extending from the medial malleolus to the navicular as above. Both of these graft procedures can be reinforced with heavy braided sutures which are available commercially (the suture brace, Arthrex, Naples Florida). However the suture brace is extremely rigid and one has to be careful with the tension that is set on the medial ankle to prevent overcorrection. Furthermore, the suture brace cannot substitute for capsuloligamentous tissue, and must be applied on the top of this tissue and never inserted as an intra-articular suture.

As mentioned previously the FDL is a weaker muscle (figure below), therefore we adopt certain techniques which would help to augment the power of the transfer. Firstly as described earlier, a peroneus brevis to longus tenodesis is performed after the calcaneal osteotomy (Figures 6, 7).

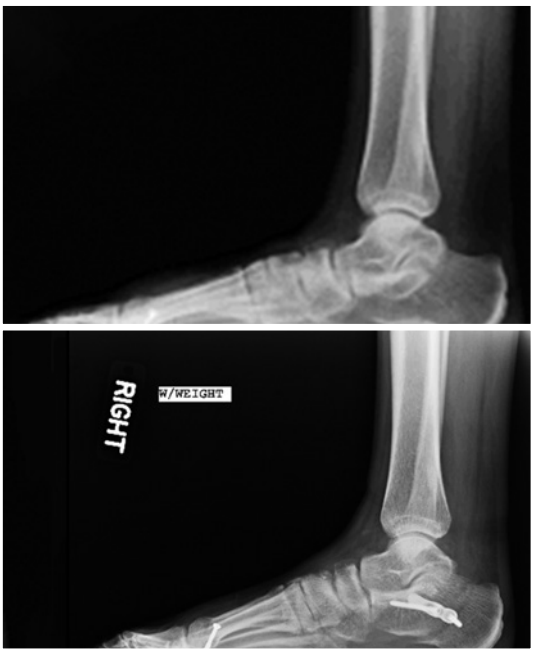

Figure 6. Radiographic appearance before and after reconstruction with a spring ligament repair. In this case, there was a rupture of the spring ligament with an associated flatfoot but the PTT was quite normal with no tenosynovitis nor rupture

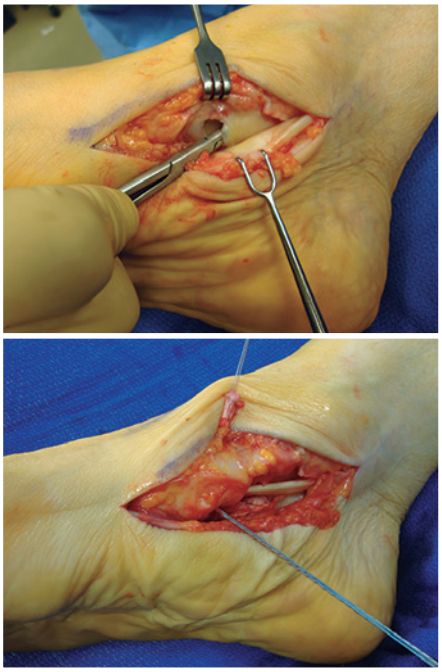

Figure 7. In this example there was a rupture of the PTT as well as a defect in the spring ligament. The FDL tendon was transferred, and a suture anchor inserted under the navicular and then a second suture anchor into the sustentaculum

The future of management of the adult acquired flatfoot deformity

It is always difficult to predict where we are going with management of the adult acquired flatfoot deformity. Certainly, as indicated above, muscles' balancing is critical, and we have approached this with a release of the deforming peroneus brevis and transfer to the peroneus longus in order to improve the balance of forces of the hindfoot. This is the one additional procedure that we would recommend routinely. The next generation of management of PTT reconstruction will involve a better understanding of the use of the PT muscle without sacrificing it's power. There are two ways in which this can be accomplished. The first is to preserve the tendon, despite the rupture, perform a repair of the tendon and then perform the FDL transfer. As we noted in the introduction, living collagen cells remain present in the ruptured tendon indicating the potential for healing. Undoubtedly the reason that this procedure failed in the early 1980's was that the rest of the foot was ignored and the forces of the torn PTT were not treated. While this is not a procedure that we routinely perform, where do you begin with excision of the torn PTT, and where do you perform a repair? Assuming that the pain from the torn tendon is the result of abnormal forces on the tendon, then various osteotomies will realign the foot, and an endoscopy of the PTT may be quite sufficient to evaluate the PTT, perform a limited debridement or guide one to opening the tendon.[8] Endoscopy of the tendon has a role, but cannot be used unless additional procedures are performed to ensure a plantigrade foot.

We have to recognize that if the PTT is ruptured, the PT muscle may still however be functioning. To avoid the problems that I note above with the muscle imbalance, surely it would be preferable to use a tendon graft to replace the torn PTT instead of the FDL transfer? In this way, you are able to preserve the power of the posterior tibial muscle. It should be understood however that if the PTT graft procedure is used, then it should not be necessary to add a peroneus brevis to longus tenodesis. This procedure is discussed in more detail below. An FDL transfer into the navicular combined with a more proximal tenodesis to the PTT could take advantage of the strength of the posterior tibial muscle to contribute to the functional transfer of the FDL (Figure 9). However, there are problems with this tenodesis procedure. Firstly, the torn PTT cannot or should not be routinely used since there may be no functioning muscle, the result of chronic rupture resulting in fatty infiltration of the muscle and permanent loss of function (Figure 8). Secondly, even

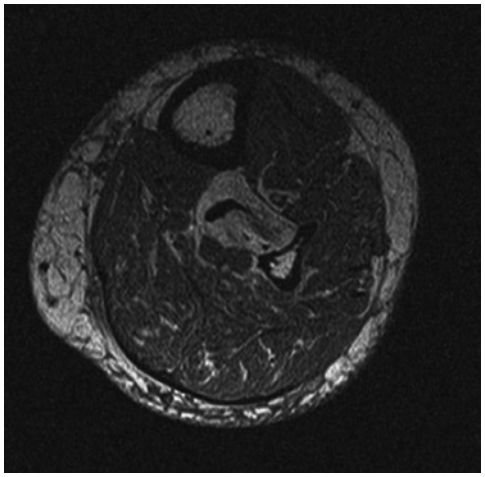

Figure 8. Note the fatty atrophy of the PT muscle in this leg. This is a contraindication to performing an allograft tendon reconstruction

Figure 9. The figure on the left (A) demonstrates the two incisions used. Note the stump of the PTT distally, which is preserved with its attachment to the navicular. This is used to reinforce the repair of the allograft when attached to the navicular through the bony tunnel. The proximal stump is sutured with a weave to the allograft as shown in the figure on the right (B)

if the muscle appears healthy on MRI, due to chronic scarring, there may be no excursion of the tendon behind the ankle due to fibrosis and adhesions of the tendon to the surrounding tissue regardless of the health of the PT muscle.

Patients with a flexible flatfoot deformity and posterior tibial tendon rupture are candidates for allograft reconstruction provided they have adequate posterior tibial muscle (on MRI) and normal excursion of the tendon at the musculotendinous junction. We therefore routinely assess the viability of the PTT muscle preoperatively with MRI of the leg muscle, not the PTT at the level of the ankle. The excursion of the PTT can only be adequately assessed intra-operatively. This procedure should be done in association with appropriate osteotomies to correct the deformity as needed according to the deformity. We obtain a MRI of the leg routinely for all patients who are candidates for allograft reconstruction in order to evaluate for fatty atrophy of the muscle. Before commencing with the planned allograft reconstruction, if still present, the excursion of the PTT is assessed and if inadequate or stuck, the allograft reconstruction is stopped and an FDL transfer performed. There are two small incisions made for the allograft procedure. The first is a distal incision which exposes the torn PTT and the navicular and the second is more proximally at the musculotendinous junction of the PTT. In this way, the flexor retinaculum is kept intact, and the allograft, once attached proximally to the PTT, it can be easily passed through the navicular and tensioned in the same way as for the FDL transfer. The diseased portion of the PTT is excised starting 6 cm distal to the musculoskeletal junction and leaving a distal stump of the PTT attached to the navicular. This distal stump will be necessary after graft passage to provide more substance for distal graft attachment. The tendon distal to the musculoskeletal junction is preserved for fixation of the proximal graft.

A stitch is passed through both ends of the allograft. The graft is passed through the PTT sheath after excising the appropriate length of the PTT and secured to the proximal PTT stump using a tendon weave suture. It may now be sutured to the tendon before it enters the navicular tunnel, the surrounding periosteum and the distal PTT stump with a #0 non absorbable suture. The portion of the tendon that will be attached distally is sized and a 4.5mm cannulated drill is drilled over a guide pin placed at the junction of the medial one-third and lateral two-thirds of the navicular. The passed tendon is laid down medially onto the plantar limb of the tendon and the distal PTT stump. As noted above in the discussion of the FDL transfer, the optimal tension for the tendon graft is still not clear. While it may make sense to suture the graft into the PTT at its resting tension, the excursion of the PTT is so short that it is our practice is to tighten the transfer such that the foot is in 10 degrees of varus at the completion of the transfer.

Following the allograft procedure, the patient is placed in a boot with an inverted heel wedge and is not permitted to bear weight. At two weeks post operatively, they are allowed to begin passive and active dorsiflexion and plantarflexion with physical therapy. They are allowed to partially weight bear at six weeks in a boot and fully weight bear at the eight weeks. They are then transitioned into a supportive ankle brace in a comfortable lace up or running shoe for an additional six weeks. Physical therapy emphasizing strengthening and balance is begun at six weeks and continued for three to six months when the patient is able to continue the rehabilitation program without assistance.

It is important to understand that there is an incredible variation in the pathology of the adult painful flatfoot deformity. In this manuscript we have focused mainly on the calcaneus osteotomy and the muscle balancing procedures. There are however many additional procedures that are required as part of the flatfoot correction which is determined by the different stages of deformity as outlined above. For example, a lateral column lengthening osteotomy is performed when the midfoot is abducted over the talus, and there is more than 40% uncovering of the talonavicular joint by the navicular. Our preference is to perform this lengthening at the neck of the calcaneus, 1.5cm proximal to the calcaneocuboid joint. A MDCO of the calcaneus is not able to correct abduction of the transverse tarsal joint since the apex of the deformity that is corrected with this translational osteotomy is the subtalar joint. There is a lot of controversy about the position of the osteotomy, ie should this be performed closer to the neck of the calcaneus and therefore avoid the potential to cross the middle facet on the medial calcaneus. This is the procedure recommended by Hintermann and we have concerns about the location of the osteotomy this far posteriorly. When one distracts the osteotomy using a pin distractor, there is the desired movement of the anterior calcaneus, but the posterior tuberosity shifts posteriorly as well. As this shift occurs, there is inevitable impingement of the edge of the osteotomy or the graft against the edge

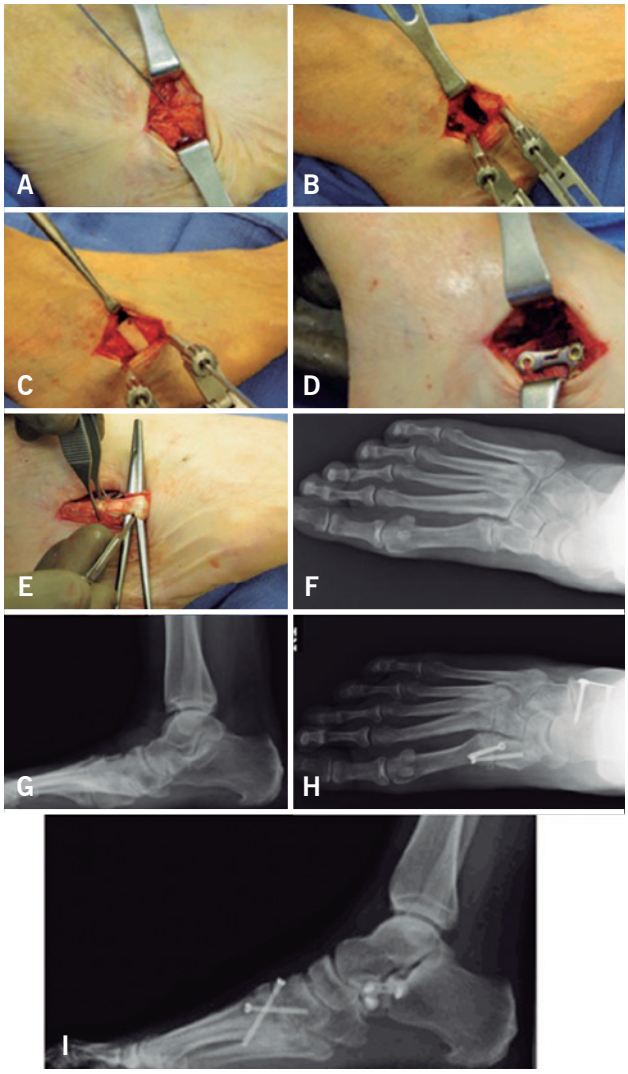

Figure 10. A) The osteotomy for the lateral column lengthening is made 1cm proximal to the calcaneocuboid joint and the location is marked with a k-wire to guide the axis of the osteotomy; B) The osteotomy is made with a saw, and then distracted approximately 8-10mm using a specific pin distractor (Paragon 28, Denver Colorado). Note the biplanar opening of the osteotomy, slightly wider dorsally and laterally; C) The graft is inserted and the pin distractor removed. D) The osteotomy is secured with a specific plate designed for a lateral column lengthening (Paragon 28, Denver Colorado); E) Due to the severity of the abduction deformity, the peroneus brevis tendon was then transferred to the peroneus longus tendon; F) This is a 54-year-old female with a rupture of the PTT, and marked abduction of the foot with uncovering of the talonavicular joint of approximately 50%; G) Note also on the lateral XR that there is marked sag at the 1st tarsometatarsal joint, which requires correction; The deformity was corrected with a transfer of the FDL, a lateral column lengthening osteotomy and an arthrodesis of the 1st tarsometatarsal joint. Note excellent coverage of the talonavicular joint (H) and good alignment of the talus with the 1st metatarsal (I).

of the posterior facet. One must always therefore open the capsule over the subtalar joint and ensure that this impingement is not present. If the impingement is noted, which in our experience is very common, then a saw must be used to shave down the bone next to the posterior facet until the range of motion no longer causes impingement.

The procedure is performed by retracting the peroneal tendons and marking the osteotomy with a k-wire 1cm proximal to the joint (Figure 10). The osteotomy is made with a saw, cutting the width of the calcaneus from lateral to medial, it is then distracted, and the size of the graft determined under fluoroscopy to ensure that good coverage of the talonavicular joint has been obtained. This is attained using a pin distractor specifically designed for this procedure. In selected cases the peroneus brevis tendon is then transferred to the peroneus longus tendon to decrease the abduction and eversion force on the hindfoot.

We believe that function of the foot will improve if the shape of the foot is completely corrected, *i.e* "function follows form" and for this reason are now routinely performing an opening wedge osteotomy of the medial cuneiform (the Cotton procedure) or an arthrodesis of the 1st TMT joint, even for cases where the forefoot supination is minimal. Although this is not done strictly according to our classification above, the addition of this osteotomy seems to improve the alignment of all the feet irrespective of the extent of forefoot supination. In addition, we have noted that by using the cuneiform osteotomy, there is far less need for an arthrodesis of either the 1st tarsometatarsal joint or the naviculocuneiform joint. The cuneiform osteotomy increases the tension on the windlass mechanism, and in doing so the radiographic instability at the adjacent joints improves.

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