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The Role of Calcaneal Osteotomies for Correction of Adult Flatfoot

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The surgical treatment of flatfoot deformity has evolved during the past three decades. Soft tissue procedures alone fail to reestablish anatomic bony alignment, and bony procedures alone fail to provide dynamic support to the arch. The goal of any procedure is to reestablish the inherently stable bony configuration with adequate soft tissue balance (tendon transfer) to maintain stability in the dynamic situation. Therefore, a combination of procedures, such as soft tissue procedures combined with calcaneal displacement osteotomies and/or lateral column lengthening, may provide optimal results. The focus of this review is the role of bony correction in the treatment of the adult acquired flatfoot deformity.

Flatfoot, or pes planus, is a combination of loss of longitudinal arch, forefoot abduction, and hindfoot valgus. The flatfoot typically is categorized as congenital or acquired, and may be differentiated using the classification of Bleck and Berzins,[7] which distinguishes between static, arthritic, and neuromuscular etiologies (Table 1).

Unilateral acquired adult flatfoot deformity is most commonly caused by insufficiency of the posterior tibial tendon,[18,43] the most powerful inverter of the foot. Once function of this tendon is lost, progressive collapse of the longitudinal arch of the foot commences. Dysfunction of the posterior tibial tendon has been stratified into three distinct stages corresponding to various grades of flatfoot deformity.[34] Stage I represents tenosynovitis and tendinitis of the competent posterior tibial tendon, and treatment for this stage of flatfoot deformity typically is limited to nonoperative measures, with consideration occasionally given to tenosynovectomy or tendon debridement. Stage II incompetence of the posterior tibial tendon leads to loss of normal alignment of the foot, but the associated flatfoot deformity remains mobile. In this intermediate stage, the bony malalignment can be corrected passively into its proper anatomic position, but the posterior tibial tendon insufficiency prevents maintenance of this corrected posture. Stage III, with severe incompetence of the posterior tibial tendon, represents progression to a fixed flatfoot deformity, which is not amenable to dynamic soft tissue balancing procedures or joint preserving osteotomies.

Mann and Thompson[43] popularized flexor tendon transfer to augment the dysfunctional posterior tibial tendon, which has met with some success in the treatment of Stage II flatfoot deformity. However, followup studies have shown that although adequate results in terms of pain and function have been achieved, soft tissue balancing procedures have proved inadequate in maintaining correction of deformity and restoring the longitudinal arch.[18,43]

Various calcaneal osteotomies and isolated bony correction, some of which date back to the

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TABLE 1. Classification of Flat Feet

Static deformities
1. Plantar flexed talus, flexible (hypermobile flatfoot)
2. Plantar flexed talus, rigid (congenital vertical talus)
3. Medial deviation of the talonavicular joint
4. Z foot with metatarsus varus
5. Calcaneal equinus

Arthritic deformities
1. Developmental (tarsal coalition)
2. Inflammatory (juvenile rheumatoid arthritis)
3. Traumatic (jumpers foot)
4. Degenerative incompetence of the first metatarsocuneiform joint

Neuromuscular deformities
1. Muscular imbalance
   a. Paralytic (spastic or flaccid)
   b. Functional (posterior tibial tendon rupture, accessory navicular)
2. Proprioreceptive imbalance (mild mental retardation, cerebral palsy, congenital blindness)
3. Collagen diseases (Marfan's syndrome, Larsen's syndrome)

nineteenth century,[20] have been described as a means of treating the unilateral adult flatfoot and restoring its bony realignment.[39,54] However, several authors have suggested that such correction is inadequate without soft tissue procedures in the treatment of Stage II flexible flatfoot deformity.[47–49]

This review addresses the role of bony correction or osteotomy in the treatment of Stage II (or flexible) adult acquired flatfoot deformity.

BACKGROUND

Normal Anatomy and Alignment

Although Rose's[52] concepts of a subtalar stool are outdated, they provide a reasonable model with which to describe the inherent stability of the foot and a means of interpreting the effects of the various surgical options in the treatment of the adult acquired flatfoot. The calcaneus represents the posterior leg of the stool, and the first and fifth metatarsals represent the two anterior legs. Rose[52] explained that this subtalar stool configuration was inherently stable, with a natural block to extension at the metatarsocuneiform articulations to maintain the arch. This concept is supported by Basmajian and Stecko,[5] who showed that no muscular activity is required to maintain the arch at midstance. Although bony configuration is essential, Rose[52] acknowledged that soft tissue restraints are important in maintaining stability of the subtalar stool. A recent investigation defined the relative contributions of bony and ligamentous structures in maintenance of the arch.[26] The study showed that 63% of the stability was provided by the bony configuration and intrinsic ligaments and that 37% of the stability was provided by a combination of spring ligament, long and short plantar ligaments, and plantar fascia.[26] Recent biomechanical studies[11,63] have supported the importance of the plantar fascia and the spring ligament complex; two investigations[37,63] defined a dynamic contribution to arch stability in stance phase from muscles about the foot and ankle.

Despite the inherent stability of the subtalar stool in maintaining the arch of the foot, Rose[52] recognized the propensity for instability when this stable platform (subtalar stool) is viewed as part of the peritalar joint complex. Sangeorzan[53] described the peritalar joint complex as a mitered hinge, functioning as a torque transmitter. For the subtalar stool to remain stable in pronation and supination, muscular activity is required. As the stool rolls into supination, plantar flexion of the first metatarsal via the peroneus longus maintains contact, whereas plantar flexion of the fifth ray via intrinsics and the posterior tibial tendon is required for pronation. Conversely, with excess pronation, the peroneus longus provides compensatory first metatarsal plantar flexion. Furthermore, with its broad insertion, the posterior tibial tendon also contributes substantially to maintaining arch stability (or preventing a flatfoot, pronated position), with tension on the plantar metatarsal bases,[35,37] and to creating an adduction moment on the forefoot.[63] Theoretically, these dynamic components contribute to maintaining the stability of the subtalar stool.

Although research to date has not completely defined the dynamic situation, principles of normal gait biomechanics may be applied to understand better the dynamic situation in the acquired flatfoot[1,2] (Alexander IJ: Foot and ankle biomechanics in normal gait, pes planus, and pes cavus. Presented at the 10th Annual Comprehensive Foot and Ankle Course of the American Academy of Orthopaedic Surgeons, Chicago, IL, November 7, 1997). In normal gait, the foot progresses from hindfoot eversion at heel strike to hindfoot inversion after midstance, before heel off. The peritalar joint complex transmits torque from the leg to foot. At heel strike, the hindfoot is in eversion, with the transverse tarsal joints in a parallel, unlocked position. By crossing the transverse tarsal joints, the posterior tibial tendon plays a major role not only in maintaining arch stability during stance phase, but also in enabling the efficient progression of the transverse tarsal joints from the unlocked to the locked position.[2,56] Subsequently, the gastrocnemius soleus complex acts on the calcaneus to invert the hindfoot additionally, locking the transverse tarsal joints and allowing for efficient force transmission for gait.[2]

The deltoid ligament has been shown to contribute to stabilization of the tibiotalocalcaneal joint complex.[23,38,60] The subtalar joint is stabilized by the talocalcaneal segment of the deltoid ligament.[38] Resnick et al[51] suggested that the deltoid ligament is a passive loadbearing structure protected by an intact, active posterior tibial tendon.

PATHOPHYSIOLOGY

Once tilted into a pronated position secondary to a compromised posterior tibial tendon, the subtalar stool cannot maintain a stable configuration.[37,52] The torque transmission from the tibia through the mitered hinge (peritalar joint complex) forces the subtalar stool into further pronation. Without the posterior tibial tendon, the stool must rely on its bony configuration and intrinsic restraints, which are adequate only if the foot is in a midstance phase.[52] These static restraints attenuate without the dynamic support of the posterior tibial tendon.[6,37,55,56] In its anatomic alignment, the Achilles tendon is an inverter of the hindfoot. With the hindfoot (calcaneus) in a valgus position, the Achilles tendon forces are redirected laterally, creating an eversion force to the hindfoot and adding to the loss of medial arch stability.[47,52] In this position, the talus is forced into a plantar flexed position, with the talar head forced plantarly and medially, additionally compromising the static restraints and creating not only the pes planus situation, but also an equinus deformity.[6,52,63] In addition, the tibialis anterior theoretically also is redirected to produce a valgus force rather than inversion as per its anatomic role.[52]

Without adequate posterior tibial tendon function, the transverse tarsal joints maintain an unlocked position and fail to progress to the locked position.[1,6,18,33,34] This leads to a loss of the rigid lever arm required for efficient push off and further contributes to the overloading of the foot or subtalar stool in an unstable, pronated position. Studies have shown that in flatfoot deformity, the intrinsic foot musculature is activated earlier, for a longer period, and over a longer arc of motion compared with the anatomically aligned foot.[41,61] In a recent study, Johnson and Harris[32] presented three-dimensional motion analysis data, comparing patients with normal anatomy with those with posterior tibial tendon insufficiency. They observed changes in all phases of the gait cycle. Extremities with posterior tibial tendon insufficiency had greater tibial abduction and external rotation; greater hindfoot plantar flexion, eversion, and internal rotation; midfoot break in the longitudinal arch before toe off; forefoot abduction; and lack of varus shift at foot off.

As noted previously, initial inversion of the hindfoot by the posterior tibial tendon locks the transverse tarsal joints, allowing the gastrocnemius soleus complex to act through the foot at the metatarsal heads.[2] In the dynamic situation, normal hindfoot inversion is lost because of posterior tibial tendon dysfunction, causing the gastrocnemius soleus complex to act at the talonavicular joint and contributing to increased stress on the talonavicular capsule and spring ligament.[6,10] This dynamic deforming force leads to the loss of the soft tissue restraint of the talonavicular articulation. Because this is forfeited with excess eccentric medial loading, the talar head becomes uncovered, leading to an abducted forefoot and additional loss of arch stability. With the foot in the pronated position, the peroneus longus is inefficient in its compensatory plantar flexion of the first metatarsal, and its forefoot abduction effect is exaggerated.[10,52,63]

Posterior tibial tendon insufficiency and hindfoot collapse into a pronated position has been associated with attenuation of the medial foot ligaments,[43] particularly the deltoid ligament.[31] A recent biomechanical investigation showed that increased forces are experienced by the deltoid ligament in a flatfoot model, simulating an attenuated posterior tibial tendon.[51] In a cadaveric model simulating a flatfoot deformity, Fairbank et al[16] described increased lateral tibiotalar joint stress.

Research has shown that static and dynamic restraints are required to maintain stability of the subtalar stool. Loss of adequate posterior tibial tendon function compromises the medial dynamic support and subsequently leads to weakening of the static supports and inherent stability of the anatomic configuration. Furthermore, the malalignment into a pronated position redirects intact dynamic structures, which have a cumulative effect on the flatfoot deformity.

CORRECTING ANATOMIC ALIGNMENT IN STAGE II DEFORMITY

Treatment Options

Compensatory mechanisms and treatment options other than bony correction are inadequate measures for the treatment of this deformity.

Natural compensatory mechanisms require sustained muscular activity of the (residual) posterior tibial tendon, Achilles tendon, and peroneus longus to reestablish bony alignment and divergence or locking of the transverse tarsal joints, ultimately resulting in fatigue, pain, and aching. A brace restores the stable bony configuration, but it must be worn full time, and, as reported by Mann and Thompson,[43] progressive arch collapse leads to additional discomfort as the head of the talus presses against the orthosis.

Repair of the ruptured posterior tibial tendon has met with limited success, and typically fails to restore its natural function.[6,18,22,36] Augmentation of the posterior tibial tendon with flexor digitorum longus transfer provides symptomatic relief but affords little anatomic correction of deformity[18,30,33,43] (Sobel M, Mann R: The results of surgical treatment for posterior tibial tendon insufficiency. Presented at the Annual Meeting of the Eastern Orthopaedics Association, Orlando, FL, 1993). Finally, it has been shown that reconstruction of the secondary ligamentous restraints (talonavicular capsule, spring ligament) reestablishes satisfactory correction initially,[10–12,19] but that the results after longer followup prove disappointing.[12,62] Furthermore, several studies suggest that patients with posterior tibial tendon disease probably have underlying hindfoot valgus,[10,19] which may predispose the foot to the development of posterior tibial tendon insufficiency.[18,30,34,36,43]

Soft tissue procedures fail to maintain normal anatomic alignment, increasing the propensity for additional deformity. The transverse tarsal joints fail to diverge and lock into a stable configuration, and the Achilles and tibialis anterior still create a valgus inducing moment. In addition, if the inherently weak flexor digitorum longus is unable to initiate hindfoot inversion, the equinus inducing forces of the maldirected Achilles tendon contribute to stress at the talonavicular articulation, weakening the secondary restraints of the talonavicular capsule and spring ligament.

Unlike soft tissue procedures, bony realignment allows for reestablishment of the normal anatomy and redirection of dynamic forces.

Calcaneal Osteotomies

History

The use of calcaneal osteotomies for the treatment of the child's flatfoot initially was advocated by Gleich,[20] who first reported his procedure in 1893. His technique involved displacement of the posterior calcaneal fragment forward, medially, and inferiorly. In the ensuing decades, various authors[40,58] reported good results using this technique. In 1959, Dwyer[14] advocated a lateral opening wedge osteotomy of the posterior aspect of the calcaneus with the use of a bone graft, and in 1975, Evans[15] described a lateral calcaneal opening wedge osteotomy just proximal to the calcaneocuboid joint.

Since the first descriptions of adult acquired flatfoot secondary to posterior tibial tendon dysfunction were presented,[21,30,34,42] the previously mentioned osteotomies were used for the treatment of this condition.[48,49]

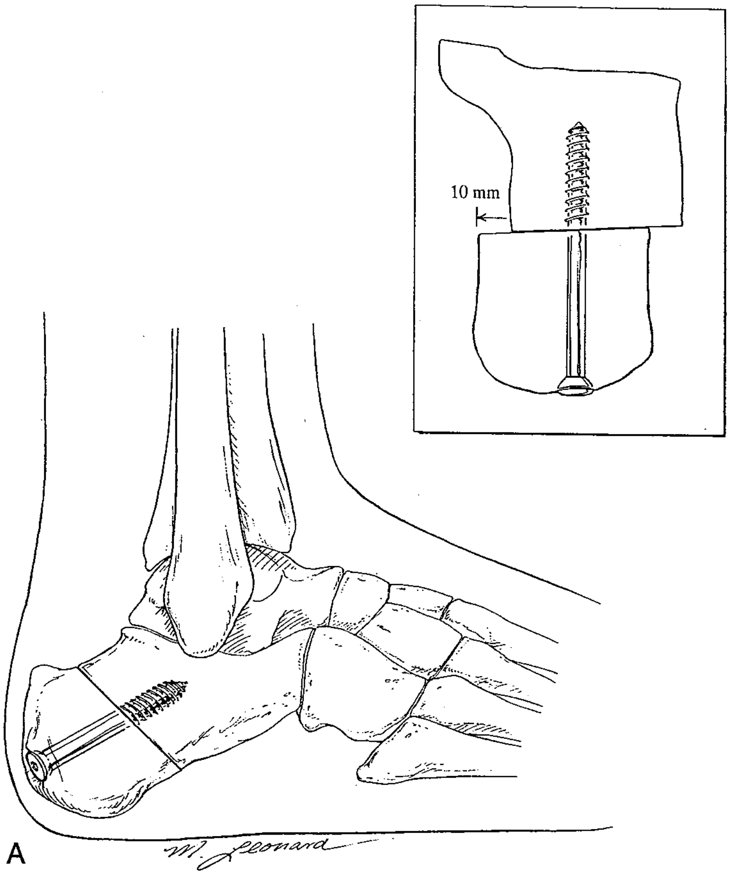
Osteotomies of the os calcis for correction of flatfoot deformity can be categorized into osteotomies at the body (Technique I) and osteotomies of the anterior part of the os calcis to lengthen the lateral column (Technique II).

Technique I: Osteotomies at the Body of the Calcaneus

Medial Calcaneal Displacement Osteotomy (Authors' Preferred Method): In 1995 and 1996, Myerson and colleagues[48,49] described the medial calcaneal displacement osteotomy and adjunctive flexor digitorum longus transfer for the treatment of posterior tibial tendon dysfunction (Fig 1). The calcaneal osteotomy used in this combined procedure was similar to that described by Gleich[20] and more recently in 1971 by Koutsogiannis.[39]

With the patient in lateral decubitus position, a 6–cm oblique incision is made behind the lateral malleolus one finger width posterior to the fibula. In this manner, the sural nerve and the peroneal tendons are anterior to the incision. The osteotomy is performed with an oscillating saw at a right angle to the lateral border of the calcaneus and is inclined posteriorly approximately 45° to the plantar surface of the hindfoot. No wedge is removed from the calcaneus, and no attempt is made to tilt the tuberosity into varus. Once the osteotomy is completed, the posterior fragment is shifted 1 cm medially. The osteotomy is secured with one cannulated screw and a hammer is used to crush the remnant edge.

Furthermore, a posteromedial incision is made in the line with the posterior tibial tendon,



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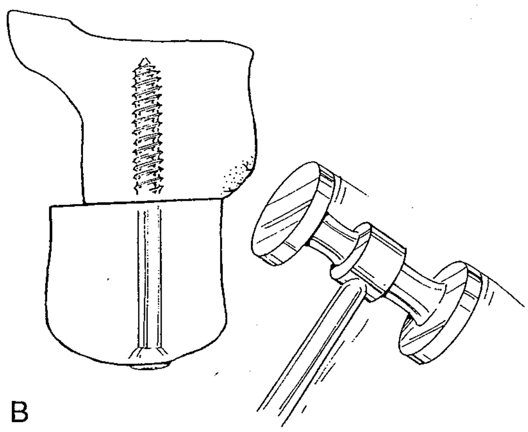

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Fig 1A–B. (A) Medial calcaneal displacement osteotomy (authors' preferred method). The osteotomy is performed with an oscillating saw at a right angle to the lateral border of the calcaneus and is inclined posteriorly approximately 45° to the plantar surface of the hindfoot. The dorsal fragment is shifted 1 cm medially (inset), and the osteotomy is closed by inserting one cannulated screw. [Modified from: Myerson MS, Corrigan J, Thompson F, Schon LC: Tendon transfer combined with calcaneal osteotomy for the treatment of posterior tibial tendon insufficiency: A radiological investigation. Foot Ankle Int 16:712–718, 1995.] (B) A hammer is used to crush the remnant edge.

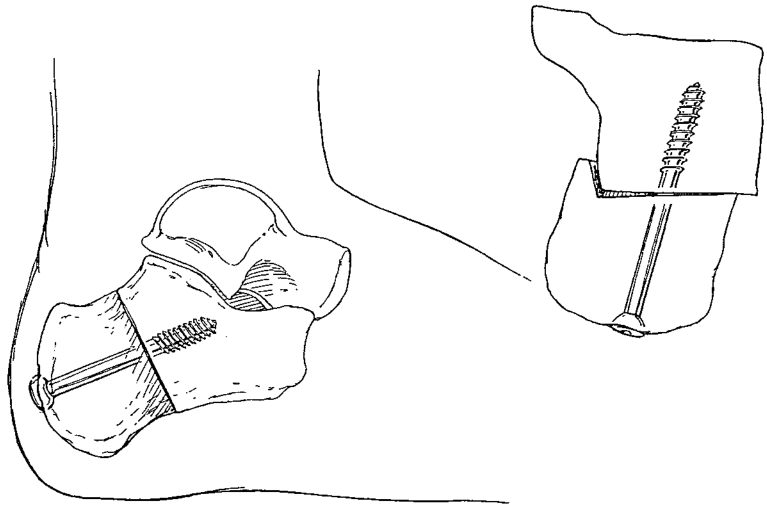

Fig 2. Rotation displacement osteotomy. The osteotomy is performed with an oscillating saw at a right angle to the lateral border of the calcaneus and is inclined posteriorly approximately 45° to the plantar surface of the hindfoot. A piece of spongeous bone, triangular in cross section, is removed. The body of the calcaneus then is moved medially approximately half of its width and tilted (inset), and the osteotomy is stabilized with two Steinmann pins or one cannulated screw.

and the posterior tibial tendon is cut distally, leaving a 1–cm stump at the attachment to the navicular. The flexor digitorum longus tendon is cut, passed through a 4.5–mm drill hole from plantar to dorsal, and secured back onto itself. The proximal cut of the posterior tibial tendon is sutured to the flexor digitorum longus tendon as a side to side tenodesis.

Rotation Displacement Osteotomy: Rose[52] suggested that, according to his stool concept, the contact area of the posterior stool leg should be moved medially (Fig 2). His favored procedure to achieve the medialization was a combined rotation and displacement osteotomy of the calcaneus.

To approach the os calcis, a lateral oblique incision is made parallel to and just below the peroneus tendons. The bone then is divided transversely, in the line of the skin incision, perpendicular to the body of the calcaneus. A piece of spongeous bone, triangular in cross section, is removed. The body of the calcaneus then is moved medially approximately half of its width and tilted. Once the proper position is obtained, the calcaneus is stabilized with two Steinmann pins (DePuy/ACE, El Segundo, CA) or one cannulated screw from the posterior aspect of the calcaneus across the osteotomy site from the posteromedial portion to the anterior portion of the calcaneus.

Crescentic Calcaneal Osteotomy: An alternate technique to that of pure medial calcaneal displacement is the crescentic calcaneal osteotomy described by Jacobs et al[29] in 1991. The concept of this procedure is to shift the posterior calcaneal fragment medially and plantarly.

A lateral incision is made superior to the lateral vault. The incision should be proximal to the peroneal tendons and should extend superior and inferior to the palpable top and bottom of the calcaneus. A small osteotome is used to create a crescentic shaped osteotomy (Fig 3). On completion of the osteotomy, the posterior calcaneal fragment is displaced in two planes. It is dis-

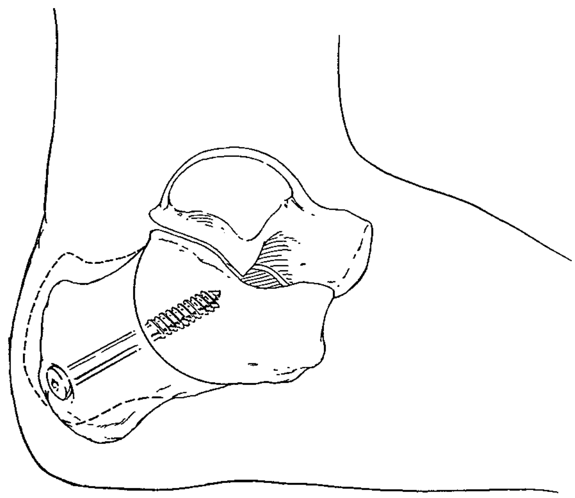

Fig 3. Crescentic calcaneal osteotomy. A small osteotome is used to create a crescentic shaped osteotomy. The calcaneal fragment then is displaced medially and inferiorly, and the osteotomy is secured with two Steinmann pins or one cannulated screw.

placed medially for a distance of ⅓ the calcaneal width, and in an effort to increase the calcaneal pitch, inferiorly. Fixation is obtained with one or two nonthreaded Steinmann pins or one cannulated screw.

Opening Wedge Calcaneal Osteotomy: The opening wedge calcaneal osteotomy[8,27] is approached through an oblique lateral incision. A lateral to medial osteotomy is accomplished with power driven instrumentation. Preoperatively, the required depth of the osteotomy is estimated by the use of calcaneal axial radiographs. A large osteotome then is used to open the osteotomy. The periosteum of the medial calcaneus should be preserved to prevent medial displacement of the posterior fragment. Once the determined width of the opening is achieved, a suitable bone graft is placed in the osteotomy (Fig 4). Fixation is obtained with two Steinmann pins or one cannulated screw.

Closing Wedge, or Reverse Dwyer, Calcaneal Osteotomy: For the closing wedge (or reverse Dwyer) osteotomy,[28] an oblique incision is made on the medial aspect of the posterior calcaneus. During a medial calcaneal osteotomy, increased attention must be given to the structures on the medial side of the calcaneus. The abductor hallucis muscle must be reflected carefully, and the medial calcaneal branch of the posterior tibial nerve must be protected from damage. Dissection is carried out straight down to the medial surface of the calcaneus, followed by subperiosteal dissection with an elevator. A suitable wedge of the calcaneus is removed, taking care not to violate the lateral wall of the calcaneus. After closure of the osteotomy and suitable position of correction, fixation is accomplished with two Steinmann pins or one cannulated screw (Fig 5).

Technique II: Osteotomies of the Anterior Part of the Os Calcis to Lengthen the Lateral Column

Lateral Column Lengthening (Evans Procedure): Another approach to the correction of bony alignment has been lengthening of the foot's lateral column (Fig 6). According to Hohmann,[24] Perthes described a procedure that includes a closing wedge osteotomy at the navicular and a lateral column lengthening at the anterior process of the calcaneus. In a clubfoot

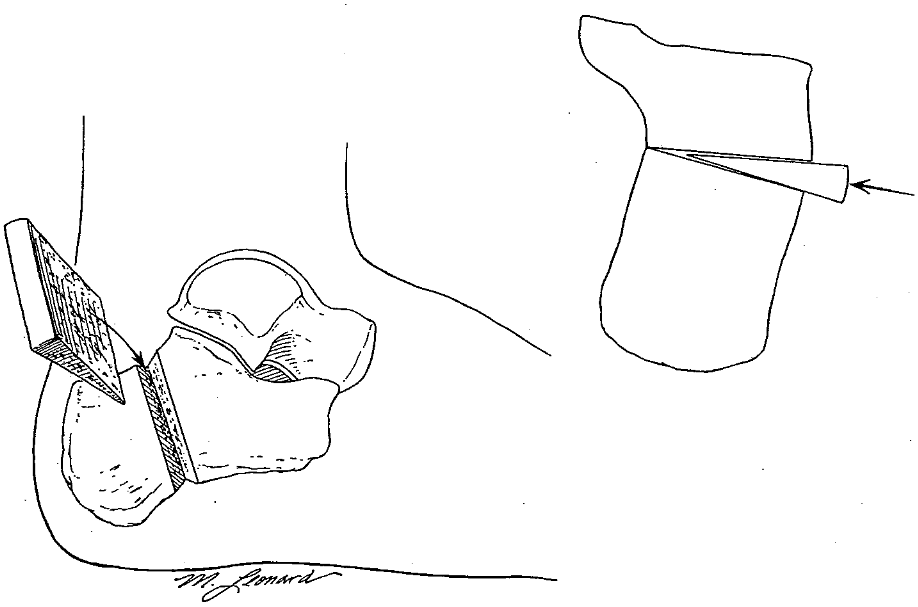

Fig 4. Opening wedge calcaneal osteotomy. A lateral to medial osteotomy is performed, and the periosteum of the medial calcaneus is preserved to prevent medial displacement. A large osteotome then is used to open the osteotomy (inset), and a suitable bone graft is placed into the osteotomy. Fixation is obtained with two Steinmann pins or one cannulated screw.

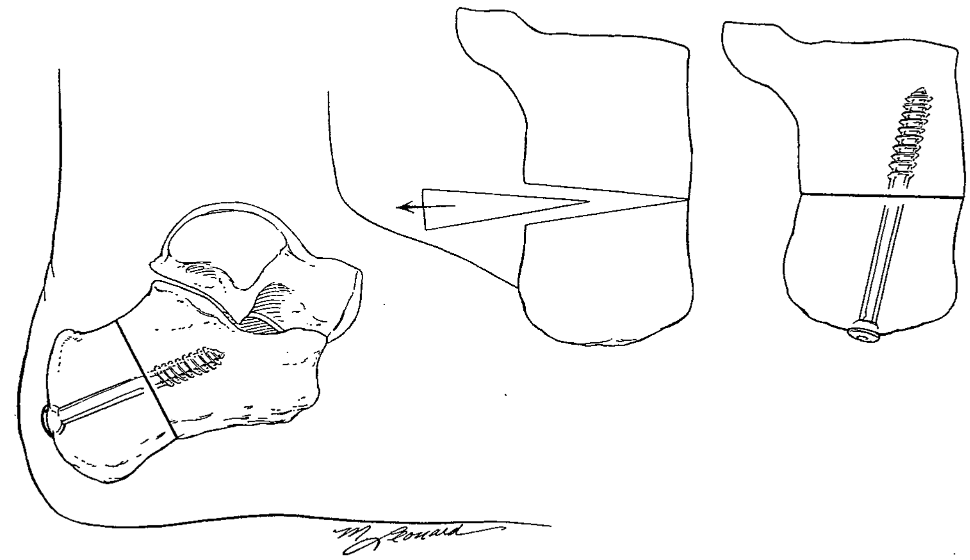

Fig 5. Closing wedge, or reverse Dwyer, calcaneal osteotomy. A suitable wedge of the calcaneus is removed (left inset), taking care not to violate the lateral wall of the calcaneus. After closure of the osteotomy and suitable position of correction, fixation is obtained with two Steinmann pins or one cannulated screw (right inset).

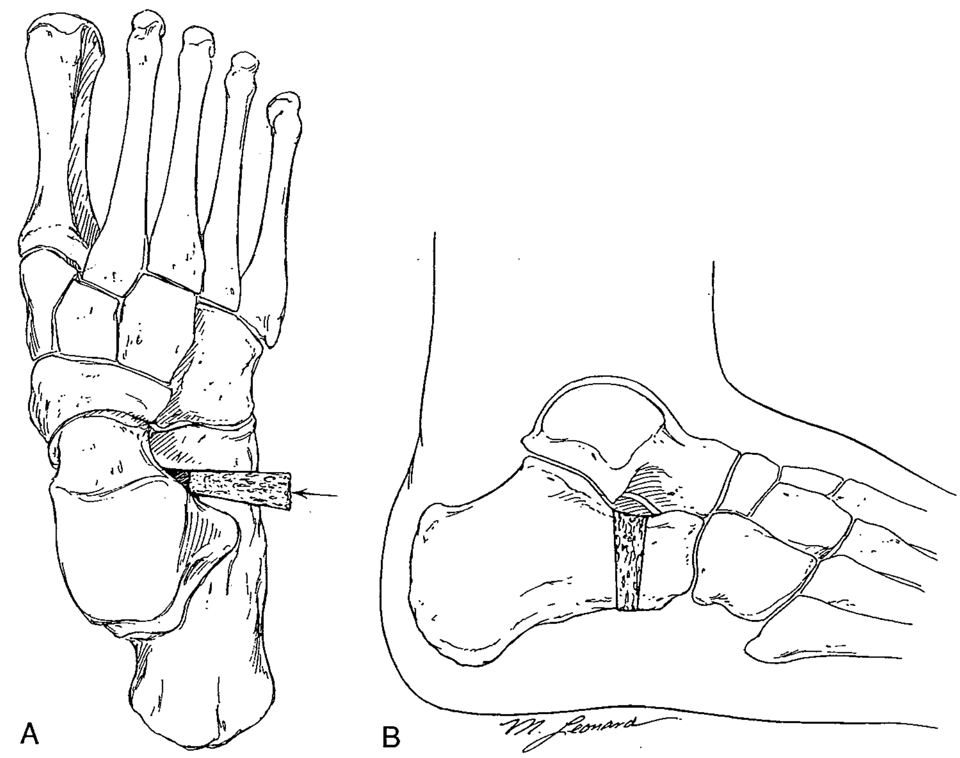

Fig 6A–B. Lateral column lengthening (Evans procedure). The calcaneus is osteomized at 4 mm proximal to the calcaneocuboid joint. The osteotomy is opened with the use of a lamina spreader. (A) A wedge shaped bicortical iliac crest bone graft is placed in the osteotomy site laterally (arrow). (B) This bone graft is slightly wider at the top. The osteotomy is secured with two Steinmann pins or one cannulated screw.

procedure, Evans[15] originally removed a wedge from the calcaneocuboid joint to abduct the forefoot. He reported that a flatfoot developed in a patient whose deformity had been overcorrected. He was able to correct the flatfoot with an opening wedge procedure and subsequently performed this procedure on all types of flatfoot.[15]

A 5–cm lateral incision is made over the calcaneocuboid joint. The peroneal tendons are isolated and retracted plantarward. The calcaneocuboid joint is identified and at 4 mm proximal to this joint, the calcaneus is osteomized. The osteotomy is opened with the use of a lamina spreader. A wedge shaped bicortical iliac crest bone graft is placed in the osteotomy site laterally. This bone graft is slightly wider at the top. After closure of the osteotomy and suitable position of correction, fixation is accomplished with two Steinmann pins or one cannulated screw (Fig 6).

Calcaneocuboid Lengthening Arthrodesis: Since the publication of a biomechanical report that suggested lengthening via calcaneal osteotomy generates excessive pressures in the calcaneocuboid joint,[9] recent lateral column lengthening studies have focused on distraction via calcaneocuboid arthrodesis[4] (Sands A, Grujic L, Sangeorzan B, Hansen Jr. ST: Lateral column lengthening through the calcaneo-cuboid joint: An alternative to triple arthrodesis for correction of flatfoot. Presented at the 25th Annual Meeting of the American Orthopaedic Foot and Ankle Society, Orlando, FL, February 19, 1995).

A lateral incision is made dorsal to the peroneal tendons and plantar to the peroneus tertius tendon, extending over the calcaneocuboid joint. The articular surfaces are removed with a straight osteotome. After distraction of more than 1 cm of the calcaneocuboid joint by a lamina spreader, a 1 cm bicortical bone graft plug is inserted. The distraction arthrodesis fixation is accomplished by an AO H plate, crossed screws, or crossed Steinmann pins.[44]

DISCUSSION

The authors' preferred method of correcting Stage II flatfoot deformity is the medial displacement osteotomy in combination with the flexor digitorum longus transfer. In 1951, Hohmann[24] reported that medial displacement osteotomy alone, as indicated by his own cases and those of Gleich,[20] was insufficient to correct the deformity. Koutsogiannis[39] reported successful correction of hindfoot valgus with medial displacement (rotational) calcaneal osteotomy, but had limited correction of the arch collapse. Although each of the patients in the study of Koutsogiannis had a mobile flatfoot deformity, posterior tibial tendon deficiency was not documented. He observed that patients with good results had improved talar head coverage. In the study by Myerson and Corrigan,[48] 32 patients were treated with this medial calcaneal displacement osteotomy in combination with the flexor digitorum longus transfer. After an average followup of 20 months, 30 patients were satisfied with the outcome of the surgery, 28 patients were able to perform repetitive single heel rises, and 23 patients were able to wear dress shoes without any support. Most patients had improvement of the talonavicular coverage and talometatarsal angles. The height of the medial cuneiform to the floor increased from a mean preoperative value of 8 mm to a mean postoperative value of 18.5 mm. The anteroposterior talometatarsal angle improved from a mean of 26° preoperatively to a mean of 6° postoperatively. On lateral projection, the mean talus first metatarsal angle improved from −28° to −13°.

Medial displacement osteotomy improves calcaneal (hindfoot) alignment and shifts the Achilles tendon insertion medially. The force of the gastrocnemius soleus complex is directed more medially, effectively transferring an antagonistic valgus inducing moment into one that assists in maintaining anatomic alignment, in static and dynamic states[47,52] (Fig 7).

Several biomechanical investigations[25,26,52,63] have reported the importance of the plantar fascia in maintaining arch stability, and it has been inferred that medial displacement calcaneal osteotomy tightens the plantar fascia. However, a recent cadaver study[25] showed that the plantar fascia actually lengthens with medial displace-

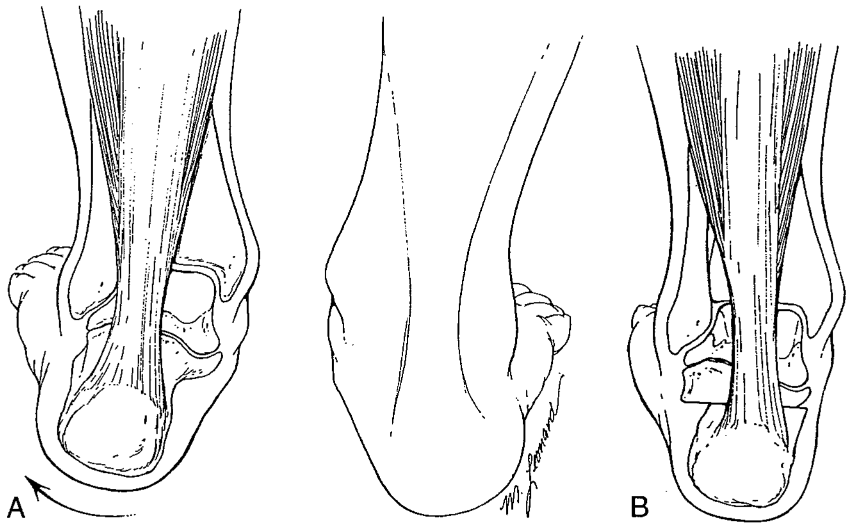

Fig 7A–B. (A) Valgus deformity of the right hindfoot. The force of the gastrocnemius soleus complex is directed laterally to the center of the subtalar joint and the long axis of the leg. (B) After calcaneal medial displacement osteotomy, the force of the gastrocnemius soleus complex is directed more medially.

ment calcaneal osteotomy, thus disproving previous theories. Therefore, it is probably the realignment of the bony structures and intrinsic ligamentous restraints that accounts for the improved arch stability in the stance phase.[5,26] Furthermore, with improved anatomic alignment, the valgus inducing force of the peroneus brevis probably is lessened, especially with the medial pull of the Achilles. Improved alignment also lessens the forefoot abducting force of the peroneus longus,[63] and it may enhance the function of the peroneus longus as a plantar flexor of the first metatarsal. However, as mentioned previously, medial displacement calcaneal osteotomy alone fails to improve arch height.[39]

Myerson and Corrigan[48] and Myerson et al[49] reported the results of a combination of medial displacement calcaneal osteotomy, flexor digitorum longus transfer, and talonavicular capsular (secondary restraint) reconstruction. Although these studies presented only clinical observations, several biomechanical advantages are inferred.

As Mann and Thompson[43] reported, the flexor digitorum longus is approximately the same diameter as the peroneus brevis, and thus is adequate for antagonistic effect. The soft tissue procedure alone, as they stated, does not correct the deformity. It only arrests the progression of the flatfoot deformity.

The double tendon transfer effect with medial Achilles shift allows for improved dynamic support of the bony realignment and compensation for the relative weakness of the flexor digitorum longus. It may be inferred that the improved alignment also restores an inversion force of the tibialis anterior, which probably further induces valgus in an acquired flatfoot deformity. In addition, with improved sagittal and coronal alignment, the peroneus longus effect of first ray plantar flexion theoretically should improve, and the effect of the peroneus longus creating an abduction moment on the forefoot should be reduced.

Medial displacement calcaneal osteotomy has been shown to reduce stress on the deltoid ligament, which serves as a secondary static restraint to pronation.[51] This also has been analyzed relative to tibiotalar joint contact stresses[16,59] (Myerson MS, Fortin PT, Cunningham BW: Changes in tibiotalar contact with calcaneal osteotomy. Presented at the 61st Annual Meeting of the American Academy of Orthopaedic Surgeons, New Orleans, LA, February 25, 1994). Medial translation of the calcaneus reduces high pressure stress zones in the lateral tibiotalar articulation of a simulated flatfoot model[16] (Myerson MS, Fortin PT, Cunningham BW: Changes in tibiotalar contact with calcaneal osteotomy. Presented at the 61st Annual Meeting of the American Academy of Orthopaedic Surgeons, New Orleans, LA, February 25, 1994).

Another approach to correction of bony alignment has been lengthening of the foot's lateral column. Traditionally, this has been accomplished using an anterior calcaneal osteotomy, as described by Evans.[15] In 1975, Evans[15] presented the results of 56 feet that underwent operative treatment for deformities resulting from poliomyelitis, idiopathic calcaneus valgus, rigid flatfoot, talipes equinovalgus, and traumatic division of the posterior tibial tendon in infancy. According to his report, the operation was successful in all cases, but no detailed analysis of the results was provided.

In 1995, Mosca[45] presented the results of the Evans procedure performed in 31 feet for severe, symptomatic valgus deformities of the hindfoot. With a followup from 2 to 3.5 years, 29 of 31 feet had a satisfactory clinical result, with creation of a longitudinal arch, elimination of the talar head prominence, eradication of pain and callusing under the talar head, and correction of the valgus deformity of the hindfoot. The lateral talar first metatarsal angle was corrected from an average of 31° preoperatively to 5° postoperatively.

Anderson and Fowler[3] presented five patients (nine feet) who underwent open calcaneal wedge osteotomies in combination with advancement of the posterior tibial tendon. After an average followup of almost 7 years, results were excellent (three feet), very good (three feet), good (two feet), and poor (one foot).

A recent radiographic study[54] suggested that lateral column lengthening improves talar head coverage by the navicular, reduces forefoot abduction, diminishes hindfoot valgus, and improves sagittal alignment of the arch. The authors concluded that significant correction of the adult flatfoot deformity could be achieved without fusion and without surgical intervention on the medial side of the foot. However, other authors (Multhopp-Stephens H, Walling A: Evaluation of lateral column lengthening versus an experimental medial reconstruction in correcting flatfoot deformity in vitro. Presented at the 25th Annual Meeting of the American Orthopaedic Foot and Ankle Society, Orlando, FL, February 19, 1995) think that lateral column lengthening is insufficient in fully correcting the pes planus deformity. This latter study suggested that anterior calcaneal osteotomy allows for correction of talonavicular subluxation, but that medial soft tissue tenodesis is required to compensate for subtalar subluxation.

It is uncertain exactly how this osteotomy corrects the pes planus deformity. It has been hypothesized that anterior calcaneal osteotomy allows for medial rotation through the heel by adduction of the calcaneus, with concomitant supination and plantar flexion.[3] Other authors[54] have suggested that the lateral column lengthening tightens the peroneus longus tendon, thus creating plantar flexion of the first ray. Another explanation has been the resultant tightening of the plantar fascia that occurs with lateral column lengthening,[45] although, as with medial displacement calcaneal osteotomy, this recently has been refuted in a biomechanical study.[25]

The concern with extraarticular lateral column lengthening through the anterior calcaneus has centered on the creation of excessive joint pressures in the calcaneocuboid articulation. Although this procedure has been accepted in the pediatric population, a recent biomechanical study[9] suggested that lengthening via calcaneal osteotomy generates excessive pressures in the calcaneocuboid joint, increasing the potential for developing arthrosis.

The focus of recent lateral column lengthening studies has been on distraction via calcaneocuboid arthrodesis[4] (Sands A, Grujic L, Sangeorzan B, et al: Lateral column lengthening through the calcaneo-cuboid joint: An alternative to triple arthrodesis for correction of flatfoot. Presented at the 25th Annual Meeting of the American Orthopaedic Foot and Ankle Society, Orlando, FL, February 19, 1995). The first short term results were presented in 1995 by Sands et al (Sands A, Grujic L, Sangeorzan B, et al: Lateral column lengthening through the calcaneo-cuboid joint: an alternative to triple arthrodesis for correction of flatfoot. Presented at the 25th Annual Meeting of the American Orthopaedic Foot and Ankle Society, Orlando, FL, February 19, 1995). They reviewed 14 patients for an average followup of 7.5 months. The talar first metatarsal angle improved by an average of 16°, and the medial cuneiform height improved by an average of 9 mm. They recommended overcorrection at surgery because loss of correction with time was observed. These authors lengthened the lateral column through the calcaneocuboid joint but supplemented the procedure with various medial soft tissue procedures, lending support to the theories of Myerson and Multhopp-Stephens[46] and Multhopp-Stephens and Walling (Multhopp-Stephens H, Walling A: Evaluation of lateral column lengthening versus an experimental medial reconstruction in correcting flatfoot deformity in vitro. Presented at the 25th Annual Meeting of the American Orthopaedic Foot and Ankle Society, Orlando, FL, February 19, 1995) that lateral column lengthening is inadequate. In addition, Sands et al (Sands A, Grujic L, Sangeorzan B, et al: Lateral column lengthening through the calcaneo-cuboid joint: An alternative to triple arthrodesis for correction of flatfoot. Presented at the 25th Annual Meeting of the American Orthopaedic Foot and Ankle Society, Orlando, FL, February 19, 1995) added an Achilles tendon lengthening to reduce equinus, which theoretically reduces the stress on medial talonavicular joint.[63] A modified Evans' procedure has been developed in which the lateral column lengthening through the calcaneocuboid joint is combined with flexor digitorum longus transfer.[4] The short term followup in a small group of patients suggests that this procedure shows promise in maintaining correction of the acquired flatfoot deformity.[57]

Calcaneocuboid fusion carries with it the risk of predisposing to adjacent joint arthrosis. One recent investigation (Astion DJ, Deland JT, Otis JC, et al: Motion of the hindfoot after selected fusions. Presented at the 25th Annual Meeting of the American Orthopaedic Foot and Ankle Society, Orlando, FL, February 19, 1995) analyzing residual motion after selected hindfoot fusion suggested that of all hindfoot fusions, calcaneocuboid fusion limited hindfoot motion and posterior tibial tendon excursion the least. This was supported by another study[13] that showed the preservation of 48% of the range of motion (ROM) in the talonavicular joint and 70% of the ROM in the subtalar joint after calcaneocuboid fusion. An additional investigation (Sands A, Harrington RM, Tencer AF, et al: The kinematics of the hindfoot with lateral column lengthening and calcaneocuboid fusion for symptomatic flatfoot. Presented at the 43rd Annual Meeting of the Orthopaedic Research Society, San Francisco, CA, February 9–13, 1997) showed that lateral column lengthening with calcaneocuboid fusion with the foot in the neutral position had no effect on hindfoot kinematics. Based on these investigations, it seems that lateral column lengthening through the calcaneocuboid joint does not necessarily place excessive stress on the adjacent joints. Considerable subtalar joint ROM is preserved after calcaneocuboid fusion, which is advantageous because limitation of subtalar joint ROM has been shown to lead to early ankle and midfoot degeneration (Sands A, Grujic L, Sangeorzan B, et al: Lateral column lengthening through the calcaneo-cuboid joint: An alternative to triple arthrodesis for correction of flatfoot. Presented at the 25th Annual Meeting of the American Orthopaedic Foot and Ankle Society, Orlando, FL, February 19, 1995).

Achilles and tibialis anterior forces are redirected to contribute dynamically to arch stability, rather than having an antagonistic effect. However, reduction of the antagonistic effect may be more important. One study has shown good results with Achilles lengthening (Sands A, Grujic L, Sangeorzan B, et al: Lateral column lengthening through the calcaneo-cuboid joint: An alternative to triple arthrodesis for correction of flatfoot. Presented at the 25th Annual Meeting of the American Orthopaedic Foot and Ankle Society, Orlando, FL, February 19, 1995). The peroneus longus tightening described by Sangeorzan et al[54] also may add first metatarsal plantar flexion, and lateral distraction probably reduces forefoot abduction imparted by the peroneus longus.[32,63] Although inherently weaker than the posterior tibial tendon, the transferred flexor digitorum longus substitutes as a dynamic medial arch stabilizer.[37] The flexor digitorum longus also can counteract the antagonistic pull of the peroneus brevis, as would occur with tendon transfer alone.[43]

In the dynamic state, the inherent weakness of the flexor digitorum longus or lengthening (and effective weakening) of the Achilles tendon may be less important, with distraction through the calcaneocuboid joint. With fusion of this joint, the transverse tarsal joints are locked partially into a biomechanically favorable position. Although some studies[13] (Astion DJ, Deland JT, Otis JC, et al: Motion of the hindfoot after selected fusions. Presented at the 25th Annual Meeting of the American Orthopaedic Foot and Ankle Society, Orlando, FL, February 19, 1995) suggest that talonavicular and subtalar joint motion are not substantially forfeited, this permanent maintenance of the locked position probably affords efficient force transmission across the foot.[1,2]

More recently, one study[50] reported short term results of a combination of the two bony procedures with tendon transfer. Despite the concern for excessive calcaneocuboid joint pressures expressed by other authors, the lateral column lengthening was performed via an anterior calcaneal osteotomy. Although medial displacement osteotomy shifted the forces of the Achilles medially, heel cord lengthening was added to reduce the equinus deformity and resultant stress of the talus on the plantarmedial talonavicular capsule. In addition, the tendon transfer procedure was through a drill hole in the cuneiform rather than the navicular to increase the lever arm of the tendon and to support the naviculocuneiform articulation, which has been reported to collapse with flatfoot deformity.[17] In this combination approach, it is difficult to ascertain which component of correction is most clinically significant, but the additive effect seems to produce promising results in maintaining correction. It remains to be seen if calcaneocuboid pressures are increased sufficiently to create a significant incidence of arthrosis.

Based on short term followup studies, medial displacement osteotomies and lateral column lengthening procedures achieve comparable results in correction of flatfoot deformities. Recent studies have favored the combination of bony realignment and soft tissue procedures, primarily because soft tissue procedures alone and bony correction alone have failed to adequately correct alignment.

The goal of any procedure remains the reestablishment of the inherently stable bony configuration with adequate soft tissue balance (tendon transfer) to maintain stability in the dynamic situation.

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