Biomechanical Consequences of Total Plantar Fasciotomy

A Review of the Literature

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Background: Plantar fascia release for chronic plantar fasciitis has provided excellent pain relief and rapid return to activities with few reported complications. Cadaveric studies have led to the identification of some potential postoperative problems, most commonly weakness of the medial longitudinal arch and pain in the lateral midfoot.

Methods: An electronic search was conducted of the MEDLINE, ScienceDirect, SportDiscus, EMBASE, CINAHL, Cochrane, and AMED databases. The keywords used to search these databases were *plantar fasciotomy* and *medial longitudinal arch*. Articles published between 1976 and 2008 were identified.

Results: Collectively, results of cadaveric studies suggested that plantar fasciotomy leads to loss of integrity of the medial longitudinal arch and that total plantar fasciotomy is more detrimental to foot structure than is partial fasciotomy. In vivo studies, although limited in number, concluded that although clinical outcomes were satisfactory, medial longitudinal arch height decreased and the center of pressure of the weightbearing foot was excessively medially deviated postoperatively.

Conclusions: Plantar fasciotomy, in particular total plantar fasciotomy, may lead to loss of stability of the medial longitudinal arch and abnormalities in gait, in particular an excessively pronated foot. Further in vivo studies on the long-term biomechanical effects of plantar fasciotomy are required. (J Am Podiatr Med Assoc 99(5): 422-430, 2009)

Plantar fasciitis is an overuse injury of the plantar fascia and the perifascial structures[1] and is considered to be a degenerative and inflammatory process.[2] Repetitive trauma produces microtears in the plantar fascia near its attachment[3]; these microtears and their attempted repair result in chronic inflammation.[4] Nonoperative treatment is successful in more than 90% of patients within 9 to 12 months of symptom onset,[2] with surgical intervention implicated for the few patients whose symptoms do not respond to conservative treatment.[5] These patients have traditionally been treated with total or partial plantar fasciotomy.[6] Few attempts have been made to study the biomechanical consequences in the foot and long-term alterations in gait after these procedures.[7]

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Methods

An electronic search was conducted of the MEDLINE, ScienceDirect, CINAHL, EMBASE, Cochrane, SportDiscus, and AMED databases. Using the keywords *plantar fasciotomy*, 913 articles published between 1976 and 2008 were identified. Limiting the search to articles that included the combination of the keywords *plantar fasciotomy* and *medial longitudinal arch* restricted the articles identified to 35. Articles that compared endoscopic and open surgical techniques were not considered to be relevant to the review. Articles that used the terms *plantar heel spur syndrome* and *plantar fasciotomy* synonymously were not considered to be specific enough for inclusion. Articles were further limited to in vivo or cadaveric studies, and studies on mechanical or mathemat-

ical models were excluded. Browsing the reference lists of these articles in conjunction with the indices of the *Journal of the American Podiatric Medical Association*, *The Foot*, *Foot and Ankle International*, *Medicine and Science in Sports and Exercise*, *The Journal of Bone and Joint Surgery*, the *Journal of Orthopaedic and Sports Physical Therapy*, *The American Journal of Sports Medicine*, and *Sports Medicine* identified an additional seven articles from the given period and two from an earlier period. Six textbook references were also relevant to the review.

Results

Plantar Fascia

Anatomy. The plantar fascia has been defined as the investing, fibrous layer of the plantar aspect of the foot, originating from the calcaneus to insert into the deep soft tissues of the forefoot, the proximal phalanges, and the skin via superficial extension.[8] It consists of three longitudinal bands covering the most superficial of the plantar muscle layers (abductor hallucis, flexor digitorum brevis, and abductor digiti minimi),[9] with each band providing an attachment for its adjacent muscle.[10]

The term *plantar fascia* can be considered to be synonymous with the term *plantar aponeurosis*, encompassing all three parts of the deep fascia of the sole.[11, 12] However, some authors believe that only the denser central portion is considered truly aponeurotic in composition, structure, and function; therefore, the thinner medial and lateral bands serve the purpose of fascial coverings for their respective underlying muscles (abductor hallucis and abductor digiti minimi).[13, 14]

The plantar fascia is approximately triangular, with a distal base and a proximal apex. Proximally, where it bears a strong attachment to the plantar medial aspect of the medial calcaneal tubercle, it is at its thickest.[15] Distally, the plantar fascia divides into five longitudinally orientated tracts, with each tract further dividing into superficial and deep tracts at a site just proximal to the metatarsal heads.[10]

Function. The foot can be described as an arch-like structure, or a "truss," in which the calcaneus and talus serve as the posterior strut, the midfoot tarsal bones and metatarsals as the anterior strut, and the plantar fascia as the "tie rod."[16] During static weightbearing, the osseous struts are compressed and the tie rod is tensed, so the plantar fascia can, therefore, be considered to function as a strong ligament that sustains tension between the rearfoot and the proximal phalanges.[17]

The plantar fascia plays an essential role in foot stability and arch morphology.[15] The tension of the plantar fascia is perceived to change significantly during gait, especially on dorsiflexion of the metatarsophalangeal joints,[9] which increases tension in the fascia and height in the arch while decreasing the length of the arch. The metatarsophalangeal joints dorsiflex at terminal stance, loading the fascia, which maintains the stability of the arch at this point in the gait cycle.[18]

This has been described as the windlass mechanism, a phenomenon where passive dorsiflexion of the hallux leads to a rise in the medial longitudinal arch, supination of the rearfoot, external rotation of the leg, and an increase in tension in the plantar fascia. Loss of this structure may have serious implications for maintaining normal gait.[18]

As the proximal phalanges hyperextend, the plantar fascia attempts to draw the calcaneus forward, shortening the distance between the metatarsal heads and the calcaneus. However, the calcaneus does not move forward in static stance; the metatarsal heads move proximally by plantarflexing, therefore increasing arch height. Because the plantar fascia is proximally attached to the medial calcaneal tubercle, increased tension in the plantar fascia will invert the rearfoot and, thereby, assist in supination. This effect is most profound with extension of the first metatarsophalangeal joint because the first metatarsal head creates a pulley with a diameter larger than that created by the lesser metatarsals.[15]

It has been assumed that the windlass mechanism assists in making the foot a more rigid structure during the propulsive phase of gait and in facilitating the foot's autosupport mechanism.[19] As the windlass unwinds, the arch flattens and the foot elongates. A compressive force is thought to be placed on the truss structures of the foot, subsequently producing tension in the plantar fascia. This results in a powerful plantarflexory force to the proximal phalanges attributable to the distal insertions of the plantar fascia winding around the plantar surface of each metatarsophalangeal joint to attach to the base of the proximal phalanges. Therefore, the plantar plate helps stabilize the proximal phalanx against the ground.[20] This can be described as the *reverse windlass mechanism*.

The plantar fascia, along with the long and short plantar ligaments and the plantar calcaneonavicular ligament, contributes to the stability of the medial longitudinal arch, as does the interlocking of the tarsal bones.[12, 21] Joint capsules and the intrinsic and extrinsic muscles also play a role, although the extent of this role has not yet been ascertained. Results of

electromyographic studies suggest that the muscles react when excessive stresses are applied to the foot, ie, during the propulsive phase of gait,[22] whereas during standing, the static structures play the most important part in medial longitudinal arch support.[21, 23]

Plantar Fasciitis

Plantar fasciitis, the most common cause of disabling hindfoot pain, is characterized by inflammation and microtearing.[24] It is typically of gradual onset, with pain at its worst first thing in the morning[25] on initiation of weightbearing.[26] The pain reduces initially with activity[25] but returns after time on the feet increases.[26] The pain is usually just anterior to the medial calcaneal tuberosity, and mild swelling may also be seen in this area.[27]

The highest prevalence of plantar fasciitis has been reported in the fifth decade of life, with a female to male predominance of 3:1,[28] although the results of other studies[29, 30] suggest that males are more commonly affected than females. The second major occurrence of plantar fasciitis is in the athletic population, representing 10% of all reported injuries to runners, irrespective of the training distance.[31]

Patient-directed treatments include regular gastrocnemius stretches, avoidance of barefoot walking, wearing supportive shoes with fastening, regularly applying ice to the affected part, and limiting physical activities. Initial conservative treatment options include padding and strapping, nonsteroidal anti-inflammatory drugs, and insole therapy. If no clinical response is noted within 6 weeks, then the patient is referred for the second phase of treatment. This is a continuation of the initial treatment options with consideration of additional therapies, such as custom orthotic devices, night splints, a limited number of corticosteroid injections, and cast immobilization.[26, 32] A clinical response to this second phase of treatment should be seen within 2 to 3 months in 80% to 95% of patients. If no response is seen, after consideration of systemic disease, surgical plantar fasciotomy is then considered.[26]

Plantar Fasciotomy

Several investigators[33-36] have advocated plantar fasciotomy for intractable symptoms of plantar fasciitis. Early studies[32-34, 37, 38] of plantar fascia release for chronic plantar fasciitis noted excellent pain relief and rapid return to activities with few reported complications. Recently, a more critical evaluation of this procedure,[7, 39] in particular complete resection of the plantar fascia, has led to identification of some possible postoperative problems, most commonly weakness of the medial longitudinal arch,[7] altered forefoot and second metatarsal loading,[40] and medial and lateral column pain.[39] Lateral column pain is synonymous with sinus tarsi syndrome, peroneal tenosynovitis, or fourth or fifth metatarsal pain. Development of lateral column pain may depend on the degree of plantar fascia release, with release of no more than 50% less likely to result in this condition.[39]

The plantar fascia under tension has been described as relieving the tensile forces from the plantar surface of the foot skeleton, which is then subjected to compressive forces only.[38] It has been strongly suggested in cadaveric studies[7, 24, 41, 42] that surgical alteration of this mechanism may lead to long-term complications and alterations in foot function.

Huang et al[41] loaded 12 cadaveric feet along the tibial axis with the specimens intact and after sequential sectioning of the plantar fascia, plantar ligaments, and calcaneonavicular ligament. Changes in the vertical and horizontal dimensions of the medial longitudinal arch were then measured. The results of this study[41] indicated that the plantar fascia is the most important structure in terms of supporting the medial longitudinal arch, followed by the long and short plantar ligaments and then the calcaneonavicular ligament. However, the medial longitudinal arch retained 63% of its "stiffness" after all three of these structures were sectioned, indicating that other static factors may contribute to arch stability.[41] The small sample size may be seen to be a limiting factor in this study. However, Huang et al[41] were confident that the consistency of the data reduced the necessity to study a larger sample.

The contribution of each of the intrinsic and extrinsic muscles in the supporting arch was not tested, so the results of this study may not apply to the dynamic in vivo foot. However, electromyographic studies have established that there is little muscular activity in vivo statically,[41] supporting the authors' concept that this experiment simulated the static weightbearing foot. Vertical arch displacement was calculated as a percentage of the relative contribution of each structure; there was no statistical analysis of the data.

Murphy et al[7] studied changes in the medial and lateral columns and the transverse arch of the foot after sequential sectioning of the plantar fascia. The plantar fascia of each of the six specimens was sectioned into thirds, from medial to lateral, 1 cm from its insertion into the calcaneus. Sixteen metal markers were inserted into designated sites, and radiographs were obtained with the specimen unloaded and then with a load of 150 pounds, obtained after cyclic loading from 0 to 150 pounds for 1,000 cycles. Translation of each marker was calculated for each

sectioning under each condition until the plantar fascia was completely released.

The metal marker positions on each radiograph were digitized, and coordinate systems were reconstructed to determine spatial position. The data were analyzed with a computer. Motion of one body relative to a fixed reference system, a moving axis system, or an arbitrarily chosen axis system could be determined from these digitized data. Motion was measured in the transverse, frontal, and sagittal planes. Significant changes in the medial, lateral, and transverse arches of the foot occurred with progressive sequential sectioning of the plantar fascia. Complete sectioning of the plantar fascia caused a 62% decline in the medial longitudinal arch and a 100% decline in the lateral column compared with release of only the medial one-third.

As in the study by Huang et al,[41] the data from the study by Murphy et al[7] were presented as percentages, without statistical analysis. Therefore, the description of significant changes in the arches of the foot with progressive sequentional sectioning is misleading because the term *significant* is being used descriptively rather than statistically.

The method was designed to simulate the weightbearing foot during the gait cycle with repetitive loading. Although digitized measurement could be considered an accurate method of data collection, the results are representative of only the weightbearing foot during the gait cycle to an extent, as muscular activity is not accounted for. The generalizability of these results must also be questioned given the small sample size of only six.

The results of the study by Murphy et al[7] support those of the study by Thordarson et al,[24] who noted progressive loss of the arch-supporting function of the plantar fascia as the fascia was sequentially sectioned from medial to lateral. Partial plantar fasciotomy decreased the arch-supporting function of the plantar fascia, and the most significant loss was noted with complete release.

Thordarson et al[24] studied the effect of partial versus total plantar fasciotomy on the windlass mechanism. Eight below-the-knee cadaveric specimens were loaded with 350 N. Arch height and length were obtained with the toes 1) resting on a plate, 2) dorsiflexed to 30°, and 3) manually maximally dorsiflexed. These measurements were taken for each division of the plantar fascia from medial to lateral in one-quarter increments of the entire width. The conclusion of this study was that the arch-supporting function of the fascia reduced progressively as the fascia was sequentially sectioned from medial to lateral. The most significant loss of the windlass mechanism was noted with complete fascial release.

Comparison of arch height and length with the 30° wedge and maximal dorsiflexion was performed with 1-way analysis of variance (ANOVA), with $P \leq .05$ considered to be significant; therefore, the results of the study by Thordarson et al[24] could be considered to be more robust than those of Murphy et al[7] and Huang et al.[41] Changes in arch length with sequential sectioning when the toes were dorsiflexed with a 30° wedge ($P = .002$) and manually maximally dorsiflexed ($P = .008$) were significant. Changes in arch height were significant with manual maximal dorsiflexion ($P = .01$) but not with a 30° wedge ($P = .1$).

Manual dorsiflexion of the toes in each specimen could have resulted in variability in the applied dorsiflexion force and may have contributed to some variability in the data. Plastic deformation could have had a variable effect and could have resulted in some inconsistency in the data. Another consideration of the reliability of this study is that rotation of the navicular may have affected the reliability of arch height measurements, although the authors acknowledged this and attempted to minimize the effect of navicular rotation by measuring arch height from the head of a cancellous screw inserted into the dorsal aspect of the navicular.[24]

Kitaoka et al[42] studied the change in position of the bones of the foot in 15 cadaveric specimens after total plantar fasciotomy in intact and destabilized feet. To assess the effect of plantar fascial release in the unstable foot, the fascia was sectioned completely in four feet after the talocalcaneal interosseous ligament, the medial talocalcaneal ligament, and the tibionavicular portion of the deltoid ligament were sectioned. Five of the cadaveric specimens were made even more unstable by sectioning the spring ligament, the long and short plantar ligaments, and the three aforementioned structures. Deformation of the plantar surface of the foot was measured after the specimens were loaded in tension to 445 N. This position of the foot at 0 N and then after loading with 445 N after fasciotomy was compared with the same before fasciotomy for each group. Significant differences in rotation were noted after fasciotomy in the five unstable feet at the talotibial joint ($P = .001$), the subtalar joint ($P = .003$), and the metatarsotalar level ($P = .007$).[42]

Obvious deformation of the arch occurred as the foot was loaded, although this deformation was severe only in the group in which the foot had been made the most unstable by sectioning of the highest number of structures. The results of this study were extrapolated to conclude that plantar fasciotomy in normal (stable) feet did not directly lead to an obvious flatfoot deformity. However, tarsal bone motion

was influenced significantly by the fasciotomy, which could be indicative of the fascia substantially contributing to the stabilization of multiple intertarsal joints. Therefore, the authors[42] suggested that total fasciotomy should not be performed in patients with a pes planus deformity owing to the risk of further deformation.

The previously mentioned studies suggest that plantar fasciotomy may have a detrimental effect on the weightbearing foot statically[24, 41, 42] and dynamically.[7] The arch-supporting function of the plantar fascia was lost progressively as the plantar fascia was sequentially sectioned, with total plantar fascia release resulting in the most significant loss of the windlass mechanism.[24] However, these conclusions were drawn from cadaver-based studies,[7] and the results of these studies were extrapolated to be representative of mechanical function in vivo when fully load bearing and in ambulation.

The most important point when considering the representation of the results of these cadaveric studies to the in vivo foot during the gait cycle is, as mentioned earlier, that the stabilizing effects of the intrinsic and extrinsic musculature were not accounted for. However, Sharkey et al[43] measured the roles of the active extrinsic musculature and the plantar fascia in foot mechanics. They examined the functional effects of fascial release in seven cadavers during terminal stance, when the combined actions of the extrinsic muscles may compensate for absence of the plantar fascia, and they evaluated the contributions of the tibialis posterior, peroneus brevis and longus, and flexor hallucis and flexor digitorum longus muscles to the stability of the medial longitudinal arch.

Heel height and tibial angle were set at points considered to be consistent with early and late terminal stance, and foot loading was achieved by simulating contraction of the gastrocnemius and soleus muscles rather than by applying direct external axial forces. Vertical ground reaction forces similar to those that occur at early and late terminal stance were developed by applying physiologic muscle forces to the aforementioned tendons with linear actuators. The effects of muscle condition and plantar fasciotomy on Achilles tendon tension, medial and lateral arch base length, arch height, and talometatarsal angle were assessed using 2-way ANOVA followed by 1-way ANOVA, increasing the reliability of the study. Significance was set at $P = .05$.

The Achilles tendon tension required to achieve target ground reaction forces at late terminal stance reduced significantly after total plantar fasciotomy ($P \leq .05$). Arch height reduced significantly at early and late terminal stance after total plantar fasciotomy ($P \leq .001$ for both). Total plantar fasciotomy resulted in significant lengthening of the medial arch base at early and late terminal stance ($P \leq .05$). Lack of activity of the tibialis posterior at late terminal stance also caused significant elongations of the medial arch base ($P \leq .05$).[43]

The design of the study by Sharkey et al[43] could be considered to be more representative of the walking in vivo foot than that of the aforementioned cadaveric studies.[7, 24, 41, 42] However, it does have limitations, the most obvious being that only the actions of the extrinsic muscles were reproduced, not those of the intrinsic muscles. The contribution of the intrinsic muscles to the integrity of the arch during the early and late phases of terminal stance are not accounted for, as acknowledged by the authors.

Heel height and tibial angle in the sagittal plane were determined at early and late terminal stance with kinematic data from Winter.[44] However, the reliability of the extrinsic muscular forces as used in the model is questionable because they are estimates of in vivo physiologic forces.

Ward et al[45] studied in vivo forces in the plantar fascia during the stance phase of gait. They evaluated whether the percentage of fascia released resulted in an increase in force in the remaining fascia. The description of this study as "in vivo" is inaccurate because data were collected from cadaveric specimens. Although a dynamic loading system was developed to allow the cadaveric specimens to replicate the stance phase of gait, and the plantar fascia force data were validated by replicating the in vivo foot mechanically using a force measuring system (F-Scan; Tekscan Inc, South Boston, Massachusetts), this study is essentially in vitro. The authors replicated the timing of in vivo muscle activity during stance in four cadaveric specimens while applying force to the tibia and fibula. The impulse in the lateral band of the plantar fascia increased throughout stance and peaked at propulsion from intact to 33% of the plantar fascia released, and it increased further when 66% of the plantar fascia was released.

Frontal plane motion of the subtalar joint was obtained with rearfoot kinematic measurement. The authors reported that when 33% of the plantar fascia was released, there was no significant increase in subtalar joint pronation during contact and early stance. The subtalar joint began to resupinate during late stance but did not resupinate to neutral before heel-off. The subtalar joint pronated normally in contact, remained pronated, and was unable to resupinate before heel-off. However, during complete fascial release, the results were inconsistent because two specimens resupinated more than when only 66% of the

fascia was released.[45] The reliability of this study is questionable because data were presented only in graph form, without statistical analysis.

There are few in vivo studies on the effect of plantar fasciotomy on arch structure and the windlass mechanism in the weightbearing foot. Daly et al[46] investigated the clinical results and evaluated the biomechanical changes across 11 years in 14 feet before and after total plantar fasciotomy. The results of this study were determined with graded subjective and objective factors. Lateral radiographs were obtained to measure soft-tissue shadow, therefore evaluating the occurrence of calcaneal heel spurs and assessing changes in longitudinal arch alignment. Force plate studies were performed to determine vertical, horizontal, and medial to lateral shear forces and the longitudinal progression of the center of pressure. Daly et al[46] mentioned radiographic evidence of the presence of a heel spur in seven of the 14 patients but are clear in their definition of plantar fasciitis as chronic inflammation of the plantar fascia secondary to microscopic fascial tears from repetitive trauma, rather than using the terms *heel spur syndrome* and *plantar fasciitis* interchangeably, as is the case in other studies.[32, 39]

Subjective evaluation postoperatively consisted of pain scores, activity limitations, and footwear limitations. Patients were assessed objectively for heel tenderness, neuropathy, and antalgic gait. Total plantar fasciotomy was considered to be successful in 71% of the 14 surgical feet, with clinical results reported as excellent for eight feet, good for two, and poor for four, although the two patients who had good results used orthoses, and one had minor restrictions of activity.

The difference in arch height preoperatively and postoperatively was significant ($P \leq .01$). Although the difference in arch length was not significant ($P = .14$), the preoperative and postoperative difference in the arch height to arch length ratio was ($P = .01$). The talo–first metatarsal angle difference was significant ($P = .05$), which, in conjunction with the differences in arch height and arch height to length ratio, suggests that plantar fasciotomy results in measurable flattening of the medial longitudinal arch. However, deformity was not recognized by any of the patients.

Force plate studies indicated persistent abnormalities of foot function despite satisfactory clinical results. Patients appeared to walk less energetically than did control subjects, placing less force on the heel and demonstrating more rapid progression of weightbearing along the longitudinal axis during the stance phase, suggesting that these patients were avoiding heel loading.[46]

The results of the force plate study by Daly et al[46] revealed a difference in loading patterns in the postoperative group compared with a control group. There was significantly less medial to lateral shear force in the postoperative group at 10% of the stance phase ($P = .2$) and significantly less vertical force at 25% of the stance phase ($P \leq .1$). Progression of the center of pressure was significantly different between the two groups at 10%, 25%, and 75% of stance ($P \leq .05$). The relevance of the force plate study is questionable because the data were measured postoperatively only and were compared with those of a control group rather than with preoperative measurements. However, it is likely that preoperative data would be skewed if patients attempted to off-load the painful area. The inclusion criteria of the control group, ie, age or sex matching, was not specified, and although the data were analyzed statistically, the method of analysis was not revealed.

Follow-up was from 4.5 to 15 years rather than acquired at standardized intervals postoperatively for each patient, which could be considered a more accurate and reliable method of obtaining data consistent with the long-term effects of this procedure. Surgical methods varied, although division of the central band of the plantar fascia was uniform in the sample studied.

A case report by Pontious et al[15] investigated the role of the plantar fascia in digital stabilization. Static foot posture and gait were analyzed objectively in a 53-year-old woman with "curling and atrophy" of the lesser digits after resection of a plantar fibroma in her right foot. To enable removal of the fibroma, a section of the plantar fascia was resected. With the patient standing in the relaxed calcaneal stance position, a decrease in longitudinal arch height was noted on her right foot compared with the left. The lesser digits appeared to be hammered, radiographically and visually. Dynamic plantar pressure studies conducted with the Musgrave Footprint System (Musgrave Systems Ltd, Wrexham, North Wales) revealed an excessively medially deviated center of pressure of the right foot compared with the left, indicative of significant overpronation of the right foot. However, there is no evidence that a medially deviated center of pressure alone represents an overpronated foot. Although it could be argued that the center of pressure measurement is supported by clinical observation, this observation was noted only statically, not dynamically, and may not have been reproduced during motion.

The force-time curve showed a more forceful push-off of the right foot consistent with the retrograde loading seen in hammer toe deformities. It can be assumed that these hammer toe deformities of the right foot developed as a postoperative complication of plantar fibroma excision.

The extended weightbearing position of the proxi-

mal phalanx, a cardinal feature of hammer toe deformity,[47, 48] may be an effect of inefficiency of the plantar structures, the intrinsic muscles, the joint capsule, and the plantar fascia.[15] Of these structures, the plantar fascia has been described as the most significant factor in stabilizing the proximal phalanx against the supporting surface.[49] In the absence or after disruption of the plantar fascia, and, therefore, with loss of the windlass effect, flexor stabilization may occur during the late stance and propulsive phases because the long flexors fire with greater force for a longer duration in an effort to resupinate the foot.[15]

The results of this case report suggest that disruption of the integrity of the plantar fascia may result in a flattened arch contour, decreased toe purchase, and a foot that functions in a more pronated state throughout the stance phase of gait.[15] However, the validity of this case study is questionable because conclusions were drawn from observational anatomical deformity and biomechanical abnormalities rather than from measured data. Further investigation is required with a larger sample size and preoperative and postoperative comparison of digital and arch structure radiographically and measured changes in gait and plantar pressure to support these results.

Discussion

Cadaveric studies identified the plantar fascia as the most important structure in terms of supporting the medial longitudinal arch, followed by the long and short plantar ligaments and then the calcaneonavicular ligament.[41] Furthermore, it has been suggested that total plantar fascia release results in loss of the medial longitudinal arch structure and in significant loss of the windlass mechanism[24] compared with partial fasciotomy.[7] It could be extrapolated from these cadaveric data that plantar fasciotomy, in particular total plantar fasciotomy, may lead to loss of the medial longitudinal arch structure and could, in turn, predispose toward complications such as posterior tibial dysfunction, flatfoot, and lateral arch pain. However, Kitaoka et al[42] concluded that plantar fasciotomy in normal (stable) feet did not directly lead to an obvious flatfoot deformity and that total fasciotomy may be contraindicated only in patients with a pes planus deformity owing to the risk of further deformation.[42]

Collectively, data from the cadaveric studies could be extrapolated to be representative of the effect of plantar fasciotomy in vivo on the integrity of the medial longitudinal arch and, therefore, the biomechanical function of the foot. Huang et al[41] reported that the medial longitudinal arch retained 63% of its stiffness after the plantar fascia, plantar ligaments, and calcaneonavicular ligament were sectioned on cadaveric specimens, suggesting that this could be indicative of other static factors contributing to arch stability. More appropriate to the effects of total plantar fasciotomy in vivo is the dynamic contribution of the musculature to medial longitudinal arch stability.

The plantar fascia is considered to be the predominant soft-tissue restraint against collapse of the arch while standing because, statically, the extrinsic muscles are relatively inactive. No arch-supporting role was detected in extrinsic muscles during cadaveric studies,[43] except in the tibialis posterior. This muscle is thought to play a major role in arch support during early and late terminal stance, and changes to the talometatarsal angle without tibialis posterior activity have been comparable with those after total plantar fasciotomy at early terminal stance.[43] This indicates that plantar fascia and tibialis posterior integrity or activity becomes increasingly important as stance progresses toward toe-off. However, in cadaveric specimens, the tibialis posterior muscle could not prevent significant arch collapse after total plantar fasciotomy. It is possible that this may not be the case in vivo because recruitment of the tibialis posterior, and perhaps the extrinsic digital flexors, may be increased as a compensatory effect of the loss of the plantar fascia and, subsequently, the windlass effect. The intrinsic musculature could also be recruited in vivo in an effort to support the medial longitudinal arch.

Although excessive recruitment of the extrinsic and intrinsic musculature could be considered to reduce the likelihood of loss of integrity of the medial longitudinal arch, it could lead to overuse injuries, such as tibialis posterior dysfunction or tendinopathy. However, Daly et al[46] reported a 71% success rate over a mean of 8 years postoperatively. Long-term postoperative complications from either overpronation of the medial longitudinal arch or extrinsic overuse secondary to plantar fasciotomy were not evident during follow-up in this sample.

Daly et al[46] evaluated biomechanical changes in 14 postoperative feet with radiographic and force plate studies. Perhaps in vivo kinematic measurement of the rearfoot postoperatively at standard intervals would be more relevant to the suggestion of plantar fasciotomy resulting in loss of integrity of the medial longitudinal arch[7, 24, 41, 42] and subsequent overpronation.

Conclusions

Results of cadaveric studies indicate that plantar fasciotomy, in particular total plantar fasciotomy, leads

to loss of stability in the medial longitudinal arch. Results of the few in vivo studies suggest that although this procedure is successful in alleviating the symptoms of plantar fasciitis in the long term, loss of the integrity of the medial longitudinal arch is apparent after fasciotomy and leads to abnormalities in gait, in particular an excessively pronated foot, which may, across time, lead to further complications. Further study of the long-term in vivo biomechanical consequences of plantar fasciotomy is required.

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