CHAPTER **34**

TRANSFER OF THE FLEXOR HALLUCIS LONGUS TENDON: A Versatile, Evidence-Based Technique

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INTRODUCTION

The use of autologous tendon transfers in the lower extremity has been implemented for many years in the correction of deformities ranging from digital contractures and hallux valgus to paralytic conditions. Nicoladoni performed the first recorded peroneus longus to Achilles transfer in Vienna in 1881. Similar techniques became popular within the American podiatric community in the early 1970s (1, 2). Despite the more recent explosion in the use of allografts and synthetic biomaterials, as well as our enhanced understanding of pedal biomechanics, there remains a marked paucity in the literature regarding specific parameters under which to utilize individual tendons. The purpose of this update is to define the role of the flexor hallucis longus tendon (FHL), discuss its anatomical and surgical considerations, and to expand upon its relevance as an ideal transfer candidate.

ANATOMY

Located in the deep posterior compartment of the leg, the flexor hallucis longus muscle originates from the inferior two-thirds of the posterior aspect of the fibula, the lower aspect of the interosseous membrane, the intramuscular septum separating it from the peroneal muscles laterally, and from the fascia covering the tibialis posterior tendon medially. It receives innervation from the tibial nerve (spinal segments L5-S2) and blood supply from the peroneal branch of the posterior tibial artery. As it runs distally, the tendon dives posteriorly behind the lower tibia and talus, passes medial to the calcaneus within its synovial sheath, crosses medial to the flexor digitorum longus (FDL) tendon through the master knot of Henry (within the second layer of the sole), and finally courses between the two heads of the flexor hallucis brevis before inserting onto the base of the distal phalanx.

The anatomical complexity of the medial column should be appreciated when harvesting of the tendon is to be performed. Attention is directed to the medial aspect of the foot, where a longitudinal incision is made above the level of the abductor extending from the navicular to the head of the first metatarsal. As the incision is deepened, both the abductor and the flexor hallucis brevis (FHB) are reflected plantarly, and a Weitlander can be utilized if necessary to assist with retraction. The origin of the short flexors may also need to be released at this point to provide adequate exposure of the deep midfoot structures (3). Identification of the FHL tendon can be assisted by gently sliding a finger over the lateral aspect of the FHB while mobilizing the hallux interphalangeal joint, and the knot of Henry can be located proximally. It is also important to avoid the medial plantar nerve and artery that should lie immediately deep and lateral to the FHL tendon. Dissection can then be carried distally as far as possible while still allowing some length for tenodesis to the FDL tendon. This can be facilitated by limited debridement of the paratenon with a #15 blade followed by anastomosis utilizing 3-0 nonabsorbable suture while all 5 digits are held in neutral to slight plantarflexion. All proximal interconnections between the two tendons are then released. This can be a delicate and tedious process as there are often multiple thick, fibrous vincula, and it is important to minimize trauma to the peritendinous tissues. The FHL tendon can then be rerouted to its appropriate transfer location proximally.

LITERATURE REVIEW

In its natural state, the flexor hallucis longus is a stance-phase muscle that is activated immediately prior to forefoot loading until just before toe off within the gait cycle. Along with its function in plantarflexion at the hallux interphalangeal joint, the muscle also assists the gastro-soleal complex in plantarflexion of the foot upon the leg. Transfer of the tendon has been described for pediatric clawtoe (4) as well as poliomyelitis (5). However, its role has become more established in addressing Achilles tendon ruptures and posterior tibial tendon dysfunction.

Achilles tendon ruptures are considered chronic or neglected if they have been left untreated for over six weeks.

End-to-end procedures, such as the Krackow, Bunnel, or lateral trap may be indicated in such cases; however, they are usually reserved for more acute scenarios in which the defect is less than 2.5 cm (6). Christensen in 1953 reported a very limited success rate (56%) and slowed healing of chronic ruptures treated with conservative versus surgical intervention in 57 cases (7). There are currently very few evidence-based protocols for selecting the best form of operative treatment. However, a detailed perusal of the more recent literature published on this topic offers some hints that may suggest a reasonable consensus.

Among the autologous tendon transfers available for Achilles tendon repairs, the most viable options reported have been the FDL and the peroneus brevis in addition to the FHL. Qu et al in 2008 retrospectively reviewed 5 patients with FDL transfers for chronic ruptures and found an overall success rate of 80% with all patients able to perform a single heel rise test at an average follow-up of 24 months. They did, however, also evaluate 8 patients in the same period with FHL transfers who demonstrated a 100% success rate, and concluded that the FHL transfer was preferred (8). Mann et al performed FDL transfers on 7 patients who demonstrated an 86% success rate at 39 months with 2 patients eventually requiring adjuvant procedures (9).

Pintore et al reported on 59 patients who received either a peroneus brevis transfer or an end-to-end repair (for acute ruptures). They revealed that most patients were generally satisfied at an average follow-up of 53 months. However, the patients with chronic ruptures experienced a higher postoperation complication rate as well as a greater loss of strength and calf circumference (10). Mafulli et al seemed to corroborate these findings when they evaluated 32 peroneus brevis transfers at 48.4 months average follow-up. Although all patients were able to perform a single heel-rise test, both calf circumferences as well as strength of the gastroc/peroneal complex were noted to have diminished significantly (11). Miskulin et al reported minimal complications in 5 patients who received peroneus brevis transfers with plantaris augmentation at 1 year average follow-up (12).

Twenty FHL transfers were evaluated by Wilcox et al who demonstrated modest findings at an average of 14 months follow-up in that only 75% of patients could perform a single heel rise test and Short Form 36 (SF-36) scores were significantly below US norms. No reruptures or residual tendinopathy was noted and the average AOFAS score was 86 (13). Martin and Manning published the accounts of 56 FHL transfers at 3.4-years average follow-up and noted a significant reduction in strength of plantarflexion. However, all but 1 patient could perform a single heel rise test, AOFAS scores had improved to 91.6, and SF-36 scores were not significantly different from US norms (14). Wong and Sing reported on 5 geriatric patients with insertional ruptures who received FHL transfers at 28.8 months average follow-up. They also demonstrated a decrease in plantarflexion strength, however, all patients were able to perform a single-leg stance, and AOFAS scores had improved from 64.4 to 94.4 postoperatively (15).

Despite some conflicting evidence in the literature reported, most authors seem to reach a consensus in emphasizing several points. The FDL tendon is beneficial in that its transfer is in-phase and does not risk off-setting the balance of inverters and everters within the foot. Also, because it is typically harvested proximal to where it divides into the digital slips, the distal stump can be reattached to the FHL to preserve function. Some authors suggest that the stump can be allowed to go free, which may be preferable in patients with pre-existing flexible hammertoes. We do not recommend this, as leaving the distal FDL tendon stumps loose will weaken the proximal stabilizing function of the lumbricales on the proximal phalanges, allowing for extensor tendon overpull and thus increasing the chance of recurrent hammertoe deformity.

Transfer of the peroneus brevis is also in-phase and its tendon is located fairly close to the Achilles. It has been reported that this transfer is less invasive in that it preserves the skin integrity over weightbearing areas (11). Furthermore, the peroneus brevis tendon provides less than half the strength of eversion as the peroneus longus, and its sacrifice does not compromise flexion at the hallux or lesser digits.

Transfer of the FHL tendon is associated with some loss of push-off strength during athletic activities (16) as well as some diminished overall plantarflexion. However, it also offers numerous advantages that appear to outweigh these factors in the majority of cases. Not only is its transfer in-phase, but the FHL axis of contraction most closely resembles that of the Achilles tendon. It is also the strongest of the transfer candidates. Silver et al analyzed calculations of the mass and fiber lengths of cadaveric specimens to describe the relative strength percentages of the muscles around the foot and ankle. The gastrosoleal complex generated a strength of 49.1% while the next strongest plantar flexor was noted to be the FHL at 3.6%. The FDL and peroneus brevis muscles were found to generate strengths of 1.8% and 2.6%, respectively (17). In addition, the FHL tendon is long (10-12 cm) allowing it to bridge a large defect, and its muscle belly aids in providing vascular supply to the distal stump of the Achilles tendon (6).

Perhaps one of the greatest advantages of the FHL transfer is its anatomic proximity that minimizes dissection without having to open other compartments. Mulier et al

Table 1

Transfer	Study	#Pts	F/U average	AOFAS	SF-36	Heel rise	Complications	% Satisfied	Good Outcome	Level of Evidence
FHL	FAI 2000	20	14m	86	< US average	75%	↓ Calf size, ROM, plantarflexion	-	-	3
	CO&RR 2005	5	28.8m	94.4	-	100%	↓ peak plantarflex torque	-	-	4
	FAI 2005	56	3.4y	91.6	=US	98%	↓ plantarflexion strength	86.4%	-	3
FDL	JBJS 1991	7	39m	-	-	-	Persistent limp, Discomfort	-	86%	3
	ZGS 2008	5	24m	-	-	100%	Weakness vs FHL transfer	-	80%	3
	FAI 2007	24	N/A	-	-	-	Nerve lesions and ruptures	-	-	4
PB	JFAS 2005	5	12m	-	-	100%	Edema, lateral instability	100%	100%	3
	Trauma 2001	59	53m	-	-	-	↓ Plantarflexion	'Majority'	-	3
	AJSM 2010	32	48.4m	-	-	100%	Infection, ↓ Gastroc/ Peroneal strength	100%	94%	4

explored this concept in another cadaver study in which the FHL and FDL tendons were released in 24 specimens. The authors recorded nerve lesions in 33% including 2 complete ruptures of the medial plantar nerve. They concluded that standard harvesting of the FHL/FDL distal to the knot of Henry may compromise the medial/lateral plantar nerve as well as other structures (18). Hence, techniques that minimize this dissection are warranted.

Among the advantages offered by the peroneus brevis transfer, its potential drawbacks should also be considered. Along with a clear loss of eversion strength, harvesting of the tendon requires greater dissection into a separate compartment, which also poses the risk of sural nerve damage when resecting the insertion from the fifth metatarsal. Finally, the technique involves re-routing the peroneus brevis tendon from lateral to medial after transfer to the calcaneus, which counteracts the inversion normally supplied by the Achilles (19) (Table 1).

With regard to posterior tibial tendon dysfunction, the literature to date is much more favorable towards transfer of the FDL tendon. This has traditionally been the treatment of choice for advanced Stage II and III cases, although, like the FHL transfer, it is often described in combination with other procedures including calcaneal osteotomies, gastroc recessions, arthroeresis, and spring ligament plication. An argument can even be made for nonoperative treatment as there is a real precedent of well-developed studies demonstrating positive long-term outcomes for patients in Stage I and II (20, 21). In their original article, Johnson and Strom only described an FDL transfer for Stage II as a means to protect the integrity of the arch. Interestingly, they argue that it is unnecessary to anastamose the distal slips to the FHL tendon because the intrinsic flexors are more than competent to prevent any functional deficits (22). This sentiment is echoed by Wacker et al who argue that the FDL and FHL tendons are conjoined distal to the knot of Henry, again reinforcing the complexity of the anatomy in this region (23).

Specific arguments in favor of the FDL over the FHL transfer for PTTD are certainly lacking. While acknowledging the superior strength of the FHL, many authors seem to hint at the location of the FDL tendon and its lateral course in line with the supinatory vector of the posterior tibial tendon (24). A common sheath has, in fact, been described for the PT and FDL tendons, which may serve as a convincing rationale in the minds of some surgeons (25). Regardless, evidence does exist to recommend the FHL in certain cases. Sammarco and Hockenbury reported on 19 Stage II transfers that resulted in AOFAS hindfoot scores improving from 62.4 to 83.6 and a very high patient satisfaction rate with only 1 patient listed as dissatisfied (26). If the supportive evidence previously outlined for Achilles ruptures can be extrapolated to the posterior tibial tendon - another stance phase muscle- then the FHL transfer in such cases can be reasonably justified.

CASE 1

The patient was a 63-year-old male veteran who presented with an approximately 5-year history of increased falling as well as worsening pain to his left Achilles tendon. He attributed these changes to a landmine that he had stepped on over 40 years earlier during his time in the service. Upon radiographic examination, he was found to have at least two calcified masses within the substance of his Achilles tendon (Figure 1). After failed conservative therapy, the decision was made to excise the calcifications along with a retrocalcaneal exostosis, and to repair the tendon with an FHL transfer.

Surgical Procedure

The decision as to how much tendon to harvest and what approach to use is made preoperatively. A common method is to take an umbilical tape or suture and place it in the direction that the tendon will be transferred. A mark is made on the strand of umbilical tape where the tendon is to end (Figure 2A). The umbilical tape is now run in the direction and course of the FHL tendon. The point that was marked on the furthest point of the umbilical tape is marked on the medial side of the foot (Figures 2B and 2C). This will determine where the incision will be placed to harvest the FHL. In our case, the FHL was to be threaded through a transverse drill hole from medial to lateral in the superior posterior calcaneus and then the end sutured side to side on the Achilles tendon.

A posterior medial incision was placed on the tendo Achillis directed transversely at the posterior superior aspect of the calcaneus, then extended distally onto the

Figure 1. Lateral view demonstrating calcifications within the body of the tendo Achillis.

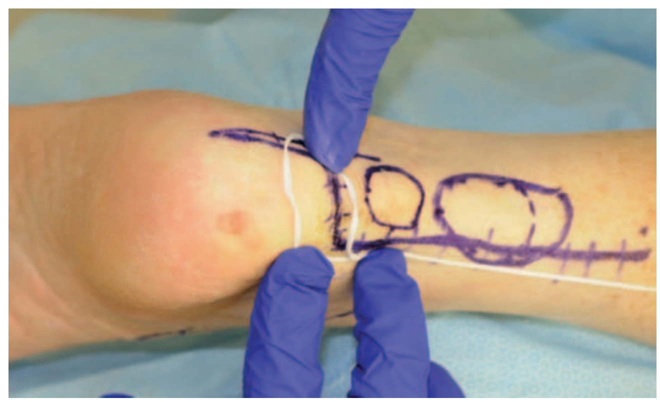

Figure 2A. Umbilical tape is run on the medial side of the Achilles tendon taking the course that the transferred FHL will take.

Figure 2B. The umbilical tape is straightened and run along the medial aspect of the foot.

Figure 2C. A mark is placed at the point at which the tendon is to be transferred.

posterior lateral side of the calcaneus (Figure 3). Following dissection, two large calcific masses were removed from the tendo Achillis. Less than 50% of the tendo Achillis was left intact (Figure 4). A decision was made to reinforce it with FHL. The tendo Achillis was retracted medially identifying the deep intramuscular septum. The septum was divided and the FHL muscle belly was clearly visualized (Figure 5). Attention was directed to the medial side of the foot where an 8-10 cm incision was made. The abductor hallucis was retracted inferiorly. The master knot of Henry was explored

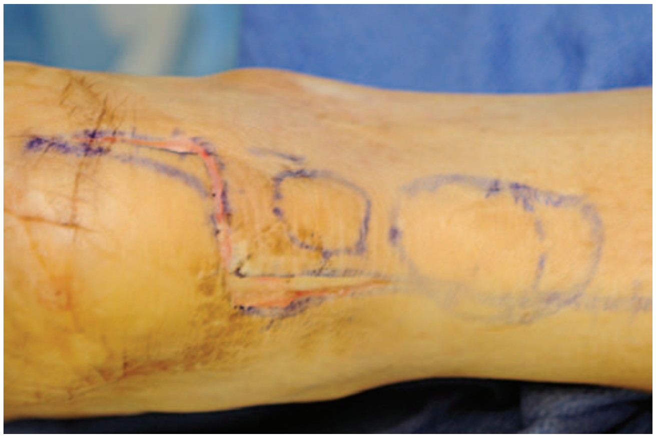

Figure 3. Incision starts linearly at the tendo Achillis, transversely at the superior calcaneus and distal laterally on the calcaneus.

Figure 4. Large calcific masses are removed from the tendo Achilles. Note approximately 50% of the Achillis tendon is left intact.

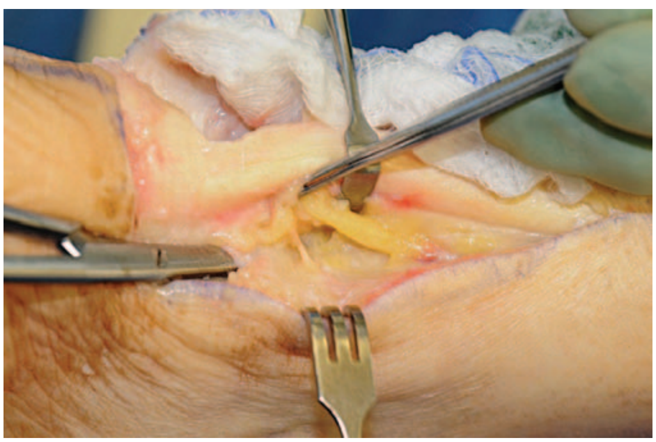

Figure 5A. Deep intramuscular septum is penetrated with a Metzenbaum scissor.

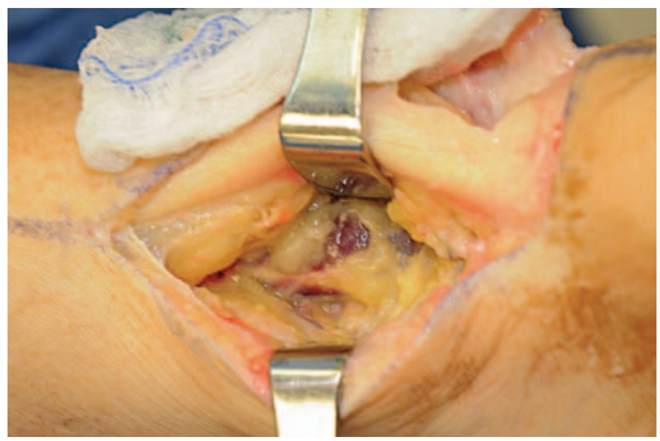

Figure 5B. The flexor digitorum muscle belly is identified deep to the intermuscular septum.

and the course of where the FHL crossed over the FDL was identified (Figure 6). While the lesser digits and the hallux are held rectus, FDL and FHL are anastomosed using a 2.0 nonabsorbable suture (Figure 7). Another 2.0 nonabsorbable suture is used to tag the most distal aspect of the FHL prior to cutting it free from the FDL. This suture allows the tendon to be manageable in such a way as to minimize its trauma (Figure 8).

Attention is then directed back to the posterior medial aspect of the ankle where the FHL is removed from within

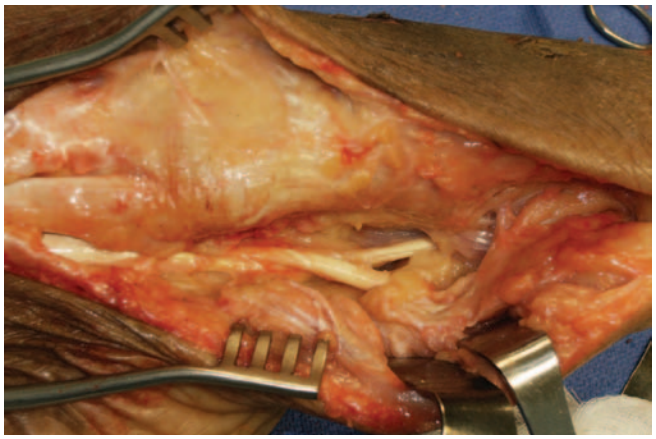

Figure 6. Anatomic specimen reveals the flexor hallucis longus crosses over the flexor digitorum longus at the level of the master knot of Henry.

Figure 7A. Medially the abductor hallucis is retracted inferiorly prior to identification of the flexor tendons.

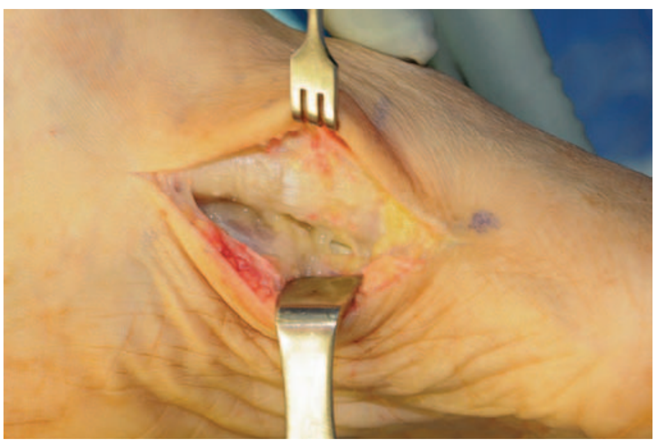

Figure 7B. Retracting the abductor hallucis.

Figure 7C. The flexor hallucis longus is sutured to the flexor digitorum longus.

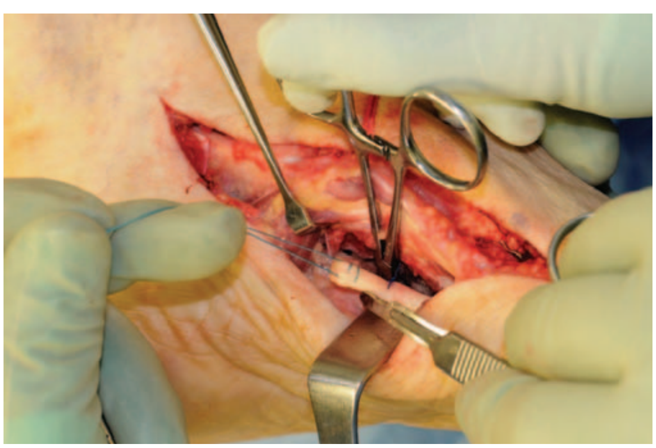

Figure 8A. A 2.0 Ethibond suture is used to tag the distal aspect of the flexor hallucis longus prior to releasing it at its anastomosis to FDL.

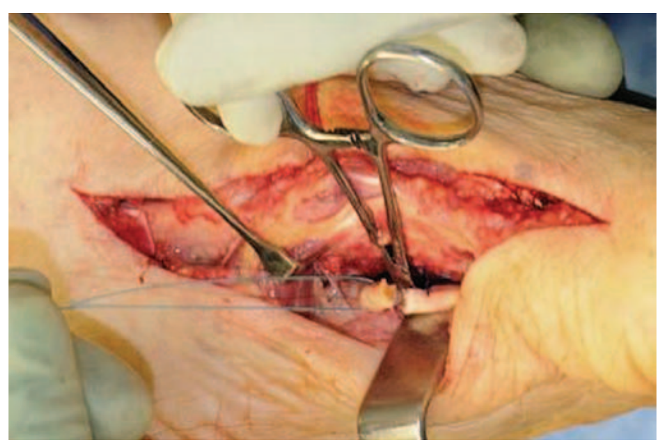

Figure 8B. Tagging the flexor hallucis longus.

its compartment (Figure 9). The tendon is passed through the distal aspect of the tendo Achillis and sutured along its medial and lateral borders (Figure 10). This deviated from the preoperative plan, which was to pass it through a drill hole in the superior-posterior calcaneus.

Postoperatively, the patient was placed in a below-knee cast and maintained non-weightbearing for approximately 4 weeks until he was transitioned to a CAM walker. At 6 weeks, he was allowed to transition to a soft shoe, and physical therapy was initiated. He was finally evaluated at 19 months following the procedure and indicated minimal pain, a significant improvement in function, and gratitude for the service provided (Figure 11, 12).

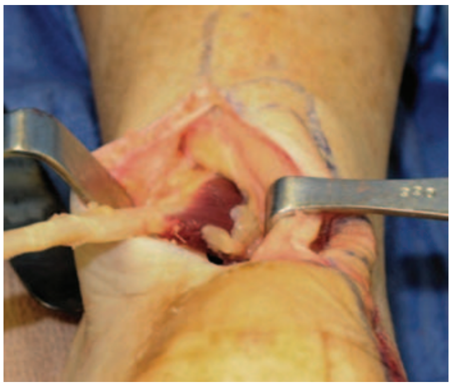

Figure 9. The flexor hallucis longus is pulled from within its compartment.

Figure 10A. The flexor hallucis longus is sutured to the tendo Achillis medially passed through the distal aspect of tendo Achillis and sutured laterally with 2.0 nonabsorbable suture.

Figure 10B. Suturing the flexor hallucis longus.

Figure 11A. Clinical evaluation at 19 months postoperative reveals excellent healing of all incision lines.

CASE 2

This individual was a 56-year-old male who presented with significant pain and deformity after having sustained several traumatic injuries to his left foot, the first of which had occurred 35 years earlier. Upon radiographic examination, he was found to have bimalleolar avulsion fractures, as well as hypertrophy and tenosynovitis of his posterior tibial tendon (Figure 13). On clinical examination, the patient was noted to have instability and pain on palpation over the avulsion fragments as well as along the course of the PT tendon and sinus tarsi. His heels both inverted upon double heel rise testing, however, he was unable to perform a left foot single heel rise test, and he demonstrated a too many toes sign on RCSP (Figure 14). The patient was diagnosed with Stage II PTTD as well as lateral ankle instability and painful bimalleolar avulsion fragments of the left ankle. A decision was thus made to proceed with surgery for the correction of the patient's deformities.

After gaining exposure laterally, a Brostrom-Gould stabilization was performed, and the lateral fragment was excised. Attention was then shifted medially, where a tenosynovectomy of the posterior tibial tendon was performed, followed by excision of the medial ossicle (Figure 15). At this point, the decision was made to proceed with an FHL transfer for the correction and augmentation of the diseased PT tendon. The incision was extended along the medial aspect of the foot, and release of the FHL tendon was performed as described previously (Figure 16). Upon mobilization and proximal migration of the harvested tendon, a 4.8-mm drill hole was placed from superior to inferior through the body of the navicular (Figure 17). A tendon passer was used to direct the FHL from inferior to superior, and tenodesis was then performed along the

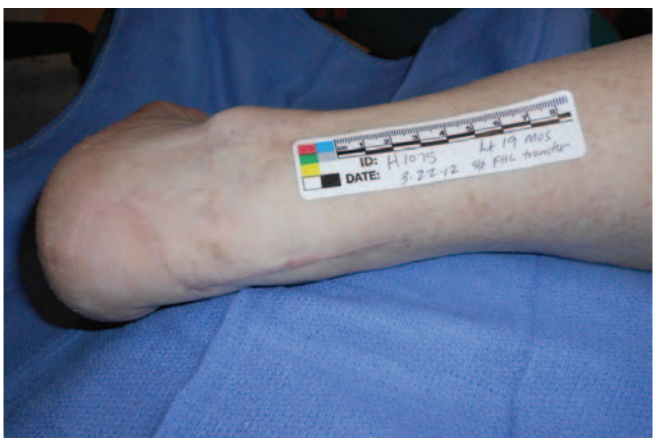

Figure 11B. Clinical evaluation at 19 months postoperative reveals excellent healing of all incision lines.

Figure 12. At 19 months postoperatively, the patient is able to perform heel-rise bilaterally.

Figure 13. T2-weighted image demonstrating increased signal intensity within the hypertrophied PT tendon.

Figure 14. Preoperative clinical view. Note the too-many-toes sign on RCSP.

proximal and distal aspects of the PT tendon utilizing 0 Ethibond (Figure 18). A short-leg cast was applied postoperatively for protection and stabilization. As of the date of this publication, the patient continues to express gratitude as he progresses towards a successful recovery.

CONCLUSION

The transfer of tendons is a novel surgical modality with many promising indications in the foot and ankle. As shown here, both chronic Achilles ruptures and PTTD have proven that they are amenable to such repairs. Based on our experience as well as evidence put forth in both the podiatric and orthopedic literature, the FHL transfer seems to provide the greatest total advantage when its location and anatomical properties are considered. The argument can perhaps most eloquently be summarized by an editorial that appeared in the 2003 *Annals of the Royal College of Surgeons of England* (27): "…The tendons used were the flexor hallucis longus, the flexor digitorum longus, and the peronei. The flexor hallucis longus transfer is considered advantageous to the other tendon transfers because it is stronger, its axis of force is close to that of the tendoachilles, and harvesting the tendon is easy and unlikely to cause any complications. We believe the flexor hallucis longus transfer to replace the tendo Achillis is a low-morbidity procedure that gives good-to-excellent results in individuals with low-to-moderate demand."

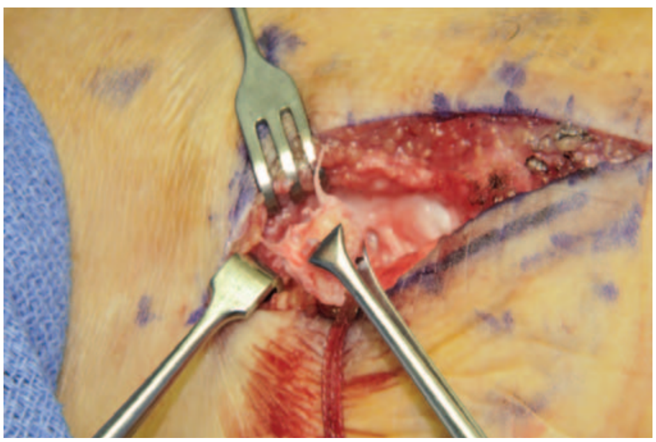

Figure 15. Excision of ossicle from tarsal tunnel.

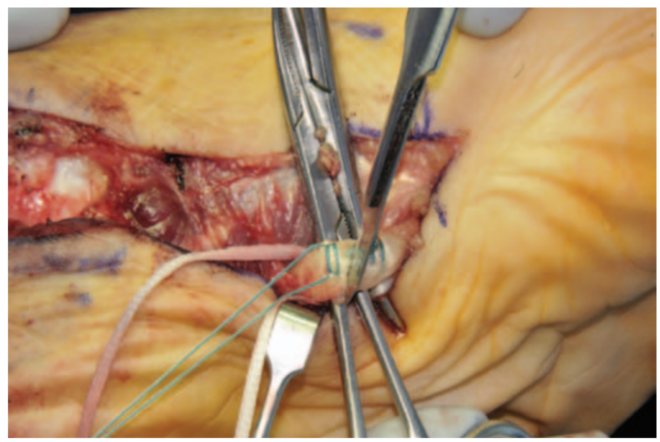

Figure 16. The flexor hallucis longus tendon is isolated and severed distally for transfer.

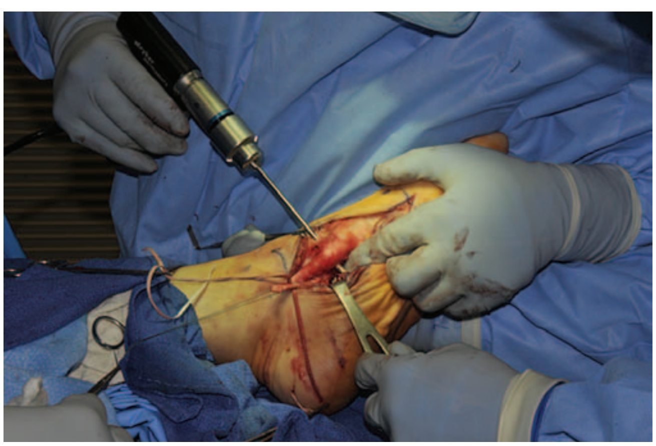

Figure 17. Drill hole through the navicular.

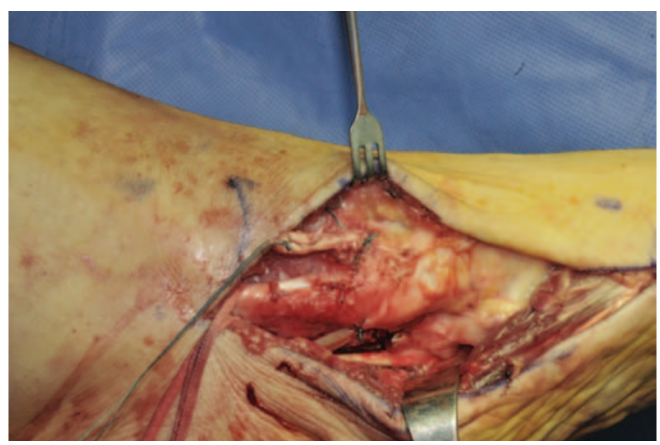

Figure 18. FHL is re-routed through the drill hole.

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