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Outcomes of flexor digitorum longus (FDL) tendon transfer in the treatment of Achilles tendon disorders☆

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ABSTRACT

Background: In patients with chronic Achilles tendon disorders, Achilles tendon debridement can be supplemented with a tendon transfer, with the flexor hallucis longus tendon (FHL) transfer representing the most common used technique. Our study describes clinical and functional results of patients treated with flexor digitorum longus (FDL) tendon transfer in the treatment of patients with chronic Achilles tendon disorders.

Methods: Retrospective study of prospectively collected data of thirteen patients (15 feet) that underwent FDL tendon transfer as part of the treatment of chronic Achilles tendon disorders. Preoperative and postoperative assessment included visual analogue score (VAS) for pain, SF-36 survey and lower extremity functional scale (LEFS). The average follow-up was 26.4 (range, 14–56) months. Patients were also assessed for ability to perform single leg heel rise test, muscle power for plantar flexion of the lesser toes, surgical scar condition and associated complications.

Results: At final follow-up, we found significant postoperative improvement in VAS score (6.6 ± 2.99 vs 1.06 ± 1.43; $p < .0001$), SF-36 physical component summary (PCS) (28.20 ± 10.71 vs 45.04 ± 11.19; $p < .0001$) and LEFS (36.13 ± 20.49 vs 58.73 ± 18.19; $p < .0001$). Twelve patients (92%) could perform a single leg heel rise test in the operated extremity, although there was significant difference when comparing operated and uninvolved sides (4.86 ± 3.36 cm vs 7.18 ± 3.40 cm; $p = .0002$). One patient reported weakness for plantar flexion of the lesser toes, without balance or gait disturbances. Two patients (2 feet, 13.3%) had superficial infections and one patient (one foot, 6.6%) needed operative debridement for a deep infection.

Conclusions: FDL tendon transfer represent an operative alternative in the treatment of chronic Achilles tendon disorders. Our study showed good clinical outcomes with low complications and donor site morbidity.

Level of evidence: Observational study, case series – level IV.

1. Introduction

Chronic Achilles tendinopathy represents one of the most common disorders of the Achilles tendon. The hallmark of chronic Achilles tendinopathy is the replacement of organized fribrillar collagen by anarchic fibrotic scar tissue. It can occur at the tendon insertion or in its midsubstance. Operative treatment is considered in patients who do not respond to conservative therapies [1]. Spontaneous ruptures might complicate the clinical course of the disease during its late stage [2], with up to 97% of the ruptured tendons presenting histological findings of chronic tendinopathy [3].

Tendon transfers represent an efficient treatment option for augmentation of the Achilles tendon debridement, especially when more than 50% of the tendon width needs to be resected [4]. Numerous techniques have been described in the literature [5–9]. Flexor hallucis longus (FHL) tendon transfer is the most widely

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used operative method and poses some advantages that include anatomical proximity and in-line pull with the Achilles, relative higher tissue strength [10], and in-phase muscle contraction with the gastrocnemius-soleus complex [11]. The incidence and importance of complications following FHL tendon transfers are subject of controversy and are poorly reported in the literature. Described disadvantages include donor site morbidity, plantarflexion weakness of the hallux interphalangeal (IP) joint, gait disturbances related to diminished push-off strength and cock-up deformity of the great toe [12]. Coull et al. reported that all 16 patients treated with FHL tendon transfers clearly demonstrated clinical and pedobarographic changes of FHL tendon function. However, findings did not translate into noticeable morbidity [13]. Schon et al. recently reported in a prospective study that the majority of 56 patients treated by FHL tendon transfer had no hallux weakness or lack of balance after the procedure [14].

Flexor digitorum longus (FDL) tendon transfer represents another operative augmentation option in the treatment of chronic Achilles tendon disorders, with possible decreased donor site morbidity. To our knowledge, there is only one study in the orthopedic literature that reported outcomes of this technique [5]. The authors have been using this surgical technique with good clinical outcomes, significant improvement in pain and function, and minimal complications or donor site morbidity.

The purpose of our study was to report clinical results of the FDL tendon transfer technique in the treatment of patients with chronic Achilles tendon disorders.

2. Material and methods

In this IRB-approved study, we retrospectively assessed prospectively collected data on patients that underwent FDL tendon transfer as part of the treatment of chronic Achilles tendinopathy between March 2012 and December 2015.

Seventeen FDL tendon transfers were performed in 15 patients with a history of chronic Achilles tendinopathy. The diagnosis was made by history and physical examination. All patients had preoperative magnetic resonance imaging of the involved extremity and failed nonoperative treatment, that included activity and shoe modification, physical therapy and anti-inflammatory medications for at least 6 months. Two patients were excluded because they could not take part in the final follow-up examination, leaving a total of 15 FDL tendon transfers in 13 patients.

Charts were reviewed to obtain preoperative demographic and clinical data, comorbidities, associated treatments, operative findings and complications. Preoperative and postoperative assessment included the following standardized questionnaires: visual analogue score (VAS) for pain, SF-36 health status survey and the lower extremity functional scale (LEFS) [15]. Surgical scar condition, ability to perform a single leg heel rise test and to walk on the tip of the toes, maximum calf circumference, Thompson's test, ability to return to prior level of sports activities and muscle power for plantar flexion of the lesser toes were recorded.

2.1. Statistical analysis

Descriptive statistics were used for the single parameters. Wilcoxon signed rank-test and paired t-test were used for comparison of preoperative and postoperative outcome scores and operated and non-operated sides, regarding maximum calf circumference (cm) and single leg raise heel distance from the floor (cm). P-values $<.05$ were considered significant.

2.2. Operative technique

The most important steps of the operative procedure are presented in Fig. 1(A–F). Patients were placed in a semi-lateral position, with the operative side down, allowing access to both the posterior and medial aspects of the foot and ankle. Three patients who have had prior surgery on the same Achilles tendon through a posterior midline approach were placed in the prone position. Operations were performed under lower limb block and general anesthesia. No tourniquet was used.

Exposure of the Achilles tendon was performed via a posteromedial incision, except in patients who had prior midline posterior approach. Dissection was performed down to the paratenon with minimal undermining to preserve a full-thickness

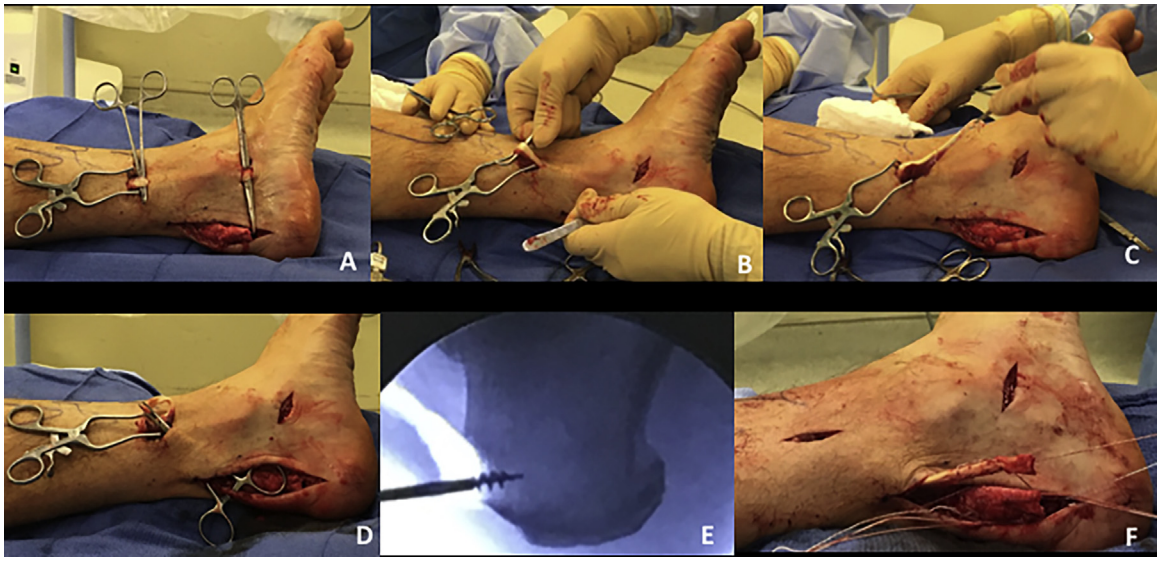

Fig. 1. (A) FDL tendon is identified distally, at the level of the talonavicular joint, and proximally, 6–10 cm above the tip of medial malleolus. (B) Tension is applied to confirm curling of the lesser toes and correct identification of the FDL tendon. (C) Tendon is transected distally and pulled out in the proximal incision. (D) Harvested tendon is delivered into the posteromedial approach, through a subcutaneous tunnel. (E) Fluoroscopic image showing the insertion of a 5.0 mm metallic anchor at posterior calcaneal tuberosity, 2 cm inferior to its dorsal aspect approximately. (F) FDL tendon is pretensioned and inserted into the calcaneus with a No. 2 polyester polyethylene suture attached to the 5.0 mm metallic anchor.

flap for closure. After proper exposure and opening of the paratenon, tendinopathic tissue was identified and fibrotic and diseased areas of the tendon were resected and/or debrided. Case-specific procedures were performed at this point.

A 2–3 cm separate incision was made longitudinally over medial aspect of the foot just over the sustentaculum talus, inferiorly to the talar neck. After proper identification of the tibialis posterior tendon (TPT) sheath, dissection was carried out deep and inferior to it aiming to isolate the FDL tendon. A clamp was passed underneath the FDL tendon and the lesser toes were moved to confirm that the appropriate tendon was identified.

An additional proximal medial incision was made 6–10 cm above the tip of medial malleolus at the posterior border of the tibia. After the sheath of the posterior compartment of the leg was opened, the FDL tendon was identified by moving the lesser toes. The FDL tendon was then transected under direct visualization at the distal incision, with the toes in maximum plantar flexion, proximally to the knot of Henry. The FDL tendon stump was carefully delivered through the proximal medial incision leaving its muscle belly intact. A clamp was used to create a subcutaneous tunnel connecting the proximal medial and Achilles tendon approach, superficially to superior flexor tendons retinaculum and down to the Achilles tendon insertion.

After proper pretensioning, FDL was attached to the calcaneus with a 5.0 mm metallic anchor and a No. 2 polyester polyethylene suture. The ideal positioning of the anchor is in the medial aspect of the posterior calcaneal tuberosity, about 2 cm inferior to its dorsal edge. To avoid impingement on the neurovascular bundle by the transferred tendon, anchor *should not* be placed in the midline or lateral calcaneus. FDL was tensioned to allow for 15–20° of ankle dorsiflexion, but the tendon was sutured with the ankle in 20° of plantarflexion. In the treatment of insertional Achilles tendinopathy cases, the Achilles tendon was completely detached from the calcaneus allowing proper insertion debridement. In these cases, a second 5.0 mm metallic anchor with a No. 2 polyester polyethylene suture was inserted in the center of the posterior surface of the calcaneal tuberosity, just at the footprint of the Achilles tendon.

Additional procedures performed included turndown flaps of the central third of the proximal aspect of the Achilles tendon (to fill gaps greater than 4 cm after tendon debridement), hamstring allograft (used to augument the treatment of one patient with a tendon gap of 8 cm after tendon debridement) and exostectomy of the posterior superior calcaneal tuberosity for Haglund's deformity.

The wounds were closed in a layered fashion, and the leg was placed in a bulky plaster-reinforced splint with the foot resting in 10–20° of ankle plantarflexion. Postoperatively, patients were kept non weightbearing in a bellow knee hinged boot with the same ankle plantarflexion for four to six weeks. At 6 weeks patients gradually increased active range of motion to neutral dorsiflexion with progressive weightbearing in the boot as tolerated until eight to twelve weeks, when they were allowed to walk without a boot.

3. Results

Thirteen patients (15 feet) agreed to participate in the study, attended for a final follow-up examination and signed an informed consent. Total of 4 males (31%) and 9 females (69%), with a mean age of 52.76 (range, 27–68) years and an average body mass index of 31.14 (range, 20.5–45.4) kg/m^2. The average follow-up was 26.4 (range, 14–56) months.

A summary of demographics, preoperative parameters and comorbidities is presented in Table 1.

Of the thirteen patients (15 feet) included in the study, seven patients (54%) had their left side surgically treated, 4 patients (31%) had right side operated and 2 patients (15%) had bilateral surgical treatment (15%). Regarding location of the Achilles tendinopathy, 8 (53%) were non-insertional and 7 (47%) were insertional. Five patients (6 feet, 40%) had a history of prior spontaneous rupture of the Achilles tendon.

A summary of surgical parameters, wound complications and reoperations is presented in Table 2. Three patients (3 feet, 20%) had a history of previous operative procedures in the same Achilles tendon, including two patients (2 feet) with failed reconstruction with tendon debridement and flexor hallucis longus (FHL) tendon transfer and one patient with tendon debridement and calcaneal exostectomy secondary to Haglund's deformity. Two patients (2 feet, 13%) had a midline posterior approach to the Achilles tendon. In both, this approach was used because they had a previous failed surgical treatment performed by the same

Table 1
Demographic parameters and preoperative data.

Patient	Sex	Age (years)	Side	Location of tendinopathy	History of Achilles tendon rupture	BMI (kg/m^2)	Comorbidities	Smoking status	Follow-up (months)
1	F	53	Bilateral	Non-insertional	Yes (bilateral)	20.48	Chronic steroids, lupus, chronic use of quinolones	Former	56/56
2	F	68	R	Insertional	No	38.2	Obesity	Former	17
3	F	50	R	Non-insertional	Yes	24.61	–	Non-smoker	35
4	M	27	R	Insertional	No	25.68	–	Non-smoker	17
5	F	47	L	Insertional	Yes	41.34	Obesity	Smoker	26
6	M	53	L	Non-insertional	No	28.73	–	Non-smoker	20
7	F	47	L	Insertional	No	21.92	–	Former	23
8	F	55	L	Insertional	No	31.96	Obesity	Former	23
9	M	54	Bilateral	Non-insertional	No	45.38	Obesity	Smoker	28/16
10	F	63	L	Non-insertional	No	27.29	Hypothyroidism, diabetes	Former	25
11	F	47	L	Insertional	No	34.36	Obesity, hypothyroidism, chronic steroids	Non-smoker	23
12	F	55	R	Insertional	Yes	31.88	Obesity, chronic steroids	Non-smoker	14
13	M	67	L	Non-insertional	Yes	32.98	Obesity	Former	17
Mean		52.76				31.13			26.4
Max		68				45.38			56
Min		27				20.48			14

Abbreviations: SD – standard deviation; Max – maximum; Min – minimum; BMI – body mass index; F – female; M – male; R – right; L – left.

Table 2
Surgical parameters, wound complications and reoperations.

Patient	Previous surgery in the Achilles tendon	Type of previous surgery	Surgical approach	Associated procedures	BMAC injection	Wound complications	Type of wound complication	Reoperation	Reoperation procedures
1	No	–	Posteromedial	None	Yes (bilateral)	None		None	
2	No	–	Posteromedial	Haglund exostectomy	No	None		None	
3	No	–	Posteromedial	None	Yes	Yes	Late deep suture granuloma (proximal posteromedial wound)	Yes	Deep granuloma ressection
4	Yes	Haglund exostectomy and tendon debridement	Posteromedial	Haglund exostectomy	Yes	None		None	
5	No	–	Posteromedial	Turndown	Yes	Yes	Deep infection	Yes	Two irrigation and debridement procedures (5 and 9 months postoperatively)
6	No	–	Posteromedial	None	Yes	None		None	
7	No	–	Posteromedial	Haglund exostectomy	No	None		None	
8	Yes	Tendon debridement and FHL tendon transfer	Posterior	Haglund exostectomy	Yes	None		None	
9	No	–	Posteromedial	None	Yes (bilateral)	Yes	Superficial infection	None	
10	No	–	Posteromedial	None	Yes	None		None	
11	No	–	Posteromedial	Haglund exostectomy	Yes	None		None	
12	Yes	Tendon debridement and FHL tendon transfer	Posterior	Turndown	Yes	None		None	
13	No	–	Posteromedial	Hamstrings allograft	Yes	Yes	Superficial infection	None	

Abbreviations: FHL – flexor hallucis longus; BMAC – bone marrow aspirate concentrate.

approach. In the other eleven patients (13 feet, 87%), the posteromedial approach was used, avoiding potential wound complications with the midline incision and making it easier to access the FDL tendon. Eight patients (8 feet, 53.3%) had associated surgical procedures in the treatment of the Achilles tendon disorder, including 5 patients (33.3%) that underwent posterior calcaneal exostectomy for Haglund's deformity, 2 patients (13.3%) that needed a turndown flap of the central third of the proximal Achilles to fill gaps greater than 4 cm after diseased tendon debridement and 1 patient (6.6%) that needed a hamstring allograft to augment an 8 cm gap after tendon debridement. Eleven patients (13 feet, 87%) underwent concomitant iliac crest bone marrow aspirate concentrate (BMAC) injections of the reconstructed Achilles tendon. The injections were performed after closure of all the layers of the wound at the level of any remaining tendinopathic tissue, Achilles reinsertion or repair and around the attachment of the transferred FDL tendon.

Two patients (2 feet, 13.3%) had postoperative superficial infection, successfully treated with oral and topical antibiotics. Deep infection was noted in one patient (one foot, 6.6%) and required operative irrigation and debridement with associated topical and oral antibiotics. Two patients (2 feet, 13.3%) had hypertrophic scar healing in the Achilles tendon approach, one of them with hypersensitivity (6.6%). There were no neurovascular complications. Until the final follow-up evaluation, 3 patients (4 feet, 26.6%) needed additional surgical procedures following Achilles debridement and FDL tendon transfer. One patient (2 feet) underwent repeated BMAC injection in both Achilles tendons 5 months after the initial operative procedure. One patient needed a resection and debridement of a late suture granuloma that occurred after 27 months of follow-up. The other patient, as mentioned above, needed two additional operative procedures for irrigation and debridement of a deep postoperative infection (respectively at 5 and 9 months after initial treatment). No mechanical failures, Achilles tendon ruptures or re-ruptures were noted.

At the time of the final follow-up examination, 6 out of 7 patients (86%) that used to participate in recreational sports before surgery returned to prior level of activities. Matles Test showed symmetrical resting tension when comparing operated and non-operated sides and Thompson test was normal in all operated limbs. Twelve patients (14 feet, 93.3%) successfully performed single leg raise test in the operated foot, including the two patients with failed FHL tendon transfer. However, when comparing operated and uninvolved sides in patients with unilateral operative procedure, we found significant difference in heel elevation during the single-leg rise test, with lower values in the operated extremity (4.86 ± 3.36 cm vs 7.18 ± 3.40 cm; $p = .0002$). In patients with unilateral treatment we also found a mean difference of 1.13 cm in the maximum calf circumference, with lower measurements in the operated leg ($37.63 \text{ cm} \pm 43.42$ vs $38.77 \text{ cm} \pm 3.4$; $p = .0005$). Five patients (38%) were not able to walk on the tip of their toes, including the two patients that had bilateral operative treatment.

Only one patient (1 foot, 6.6%) reported weakness for plantar flexion of the lesser toes, without associated balance or gait disturbances. All patients (100%) had 5/5 muscle power for plantarflexion of the lesser toes.

Comparative analysis between pre- and postoperative scores is presented in Table 3. With the data available, we found significant clinical improvement when comparing preoperative and final

Table 3
Comparative analysis of outcome scores (Wilcoxon signed rank-test and paired t-test).

	VAS pain	LEFS	SF-36 PCS	SF-36 MCS
Postoperative score	1,06667	58,7333	45,0467	51,5333
Preoperative score	6,6	36,1333	28,2067	56,7533
Mean difference	−5,5333	22,6	16,84	−5,22
Standard error	0,68914	4,16196	2,29488	3,31732
Upper 95% CI	−4,0553	31,5265	21,762	1,89494
Lower 95% CI	−7,0114	13,6735	11,918	−12,335
P-value	<.0001	<.0001	<.0001	.1379

Abbreviations: VAS – visual analogue scale; LEFS – lower extremity functional scale; SF – short form; PCS – physical component summary; MCS – mental component summary.

follow-up postoperative VAS scores (6.6 ± 2.99 vs 1.06 ± 1.43; $p < .0001$), SF-36 PCS (28.20 ± 10.71 vs 45.04 ± 11.19; $p < .0001$), and LEFS (36.13 ± 20.49 vs 58.73 ± 18.19; $p < .0001$). No differences were found for the SF-36 MCS (56.75 ± 9.40 vs 51.53 ± 12.95; $p = .138$). No differences were found in pre-operative and post-operative scores when comparing results for patients with insertional tendinopathy, non-insertional tendinopathy and history of prior spontaneous rupture of the Achilles tendon (Fig. 2).

4. Discussion

Flexor hallucis longus (FHL) tendon transfer is an accepted treatment option for both chronic tendinopathy and chronic rupture of the Achilles tendon [9,14,16]. The FHL tendon has a relative good strength, parallel axis of contractile force and an in-phase activity with the gastrocnemius-soleus muscle and a close proximity with the Achilles tendon, making it suitable as a donor source for operative repair augmentation [6,11,17]. This operative technique has shown good results in several studies with associated improvement in pain, ankle plantar flexion strength, and functional outcome scores [6,9,13,14,16,18]. However, most of these studies did not detail results concerning postoperative functional and donor site morbidity associated with FHL tendon transfers, especially regarding push-off weakness and gait disturbances. These complications may be more readily noticed in younger and more active patients.

Hartog, in a retrospective study with 26 patients with chronic Achilles tendinopathy treated with FHL tendon transfer, reported that all patients lost some of the flexion strength at the hallux interphalangeal joint (IPJ), but none of them had functional complaints including gait problems or toe-off weakness [7]. Another retrospective study with 16 patients with chronic Achilles tendon ruptures treated with similar technique demonstrated absence of active plantarflexion of the hallux IPJ in all patients and a tendency for reduced total peak pressure loading of the distal phalanx of the hallux in pedobarography studies [13]. Hahn et al., in a study with 13 patients treated by FHL tendon transfer, described no clinical asymmetry on barefoot gait and no limping during normal walking or stair climbing. However, all patients had significant reduction of active flexion of the 1st metatarsophalangeal joint (MTPJ) and 1st IPJ and also altered findings on pedobarography studies, including unloading of the hallux and load transfer to the metatarsal heads [12]. Richardson et al. described significant decreased pedobarographic distal phalangeal pressure of hallux in 24 patients with chronic tendinopathy or rupture of the Achilles tendon, treated by the same operative technique [19].

In a study with 20 patients who underwent FLH transfer for treatment of Achilles chronic tendinopathy, Wilcox et al. showed that 25% of patients were not able to perform a tip-toe stance on the operated side [9]. In a prospective study involving 46 patients with chronic Achilles tendinopathy treated by FHL tendon transfer, Schon et al. reported that only 76% of patients reported no lack of balance during gait [14]. In the present study, no patient reported gait disturbances and all but one patient (14/15 feet, 93.3%) were able to perform a single leg heel rise [14].

The transfer of the flexor digitorum longus (FDL) tendon represents an alternative operative technique with the advantage of keeping the FHL tendon intact, preserving the push-off strength and minimizing reported gait disturbances. Therefore, it is our understanding that it should be highly considered in the treatment of young and active patients with chronic Achilles tendon disorders.

To our knowledge, our study is the largest case series and the second to report clinical results of FDL tendon transfer in the treatment of chronic Achilles tendinopathy. Mann et al. described good to excellent results at 39 months follow-up in six out of seven patients (85.7%) that underwent this operative procedure [5]. However, no standardized outcome scores or questionnaires were used.

In the current study, we found significant improvement of VAS score, SF-36 physical component summary (PCS) and LEFS in patients with chronic Achilles tendinopathy that underwent tendon repair and augmentation with FDL tendon transfer. Most of the patients were able to walk on the tip of their toes and to perform a single-leg heel rise in the operated foot, including two patients with prior failed FHL tendon transfer reconstruction. Regarding functional complications, only one patient (6%) reported weakness for plantar flexion of the lesser toes, but no balance or gait disturbances. No mechanical failures of the operative reconstruction were found. We also had relative low incidence of wound complications, that included superficial infection (13.3%), deep infection (6.6%), hypertrophic healing (13.3%) and wound hypersensitivity (6.6%).

Our technique was different from the proposed by Mann et al. [5]. The harvesting of the FDL tendon was performed at the level of the talonavicular joint, and not distally in the arch of the foot. We believe that avoids potential injury to medial and lateral plantar nerve during midfoot dissection [20,21], and preserve interconnection between FDL and FHL in the midfoot, which might contribute to residual function of lesser toes [22]. The use of similar subcutaneous tunnel has been previously described in the treatment of patients with spastic equinovarus deformity secondary to upper motoneuron syndrome [23]. We also used a separate incision, proximally to the flexor tendons retinaculum, to retrieve the FDL tendon out of the tarsal tunnel, passing it distally through a subcutaneous tunnel that allowed a better gliding and avoided the transfered tendon to wrap around neurovascular bundle inside the tarsal tunnel. Another difference was the method of fixation, since we used suture anchors instead of a transosseus sutures. Although the use of a single suture anchor does not seem to be a strong fixation technique, it gave enough strength for proper tensioning and transfer of the FDL.

We believe that relying only on the strength of FDL would not be enough to maintain the function of the gastrocnemius-soleus complex. Therefore, we preserved as much Achilles tendon tissue as possible in all cases, making judgement of tendon length clinically easier and keeping it as a scaffold for the FDL tendon transfer to heal [7,24,25]. In patients that we had to sacrifice a large tendon segment, we performed a turndown of the central third of the proximal aspect of the Achilles tendon or hamstring allograft reconstructions.

Limitations of this study includes: absence of a control group; retrospective design; limited number of patients enrolled; combined evaluation of patients with different types of chronic Achilles tendinopathy (insertional and non-insertional) and patients with history of prior spontaneous ruptures; use of associated operative procedures, including BMAC injections.

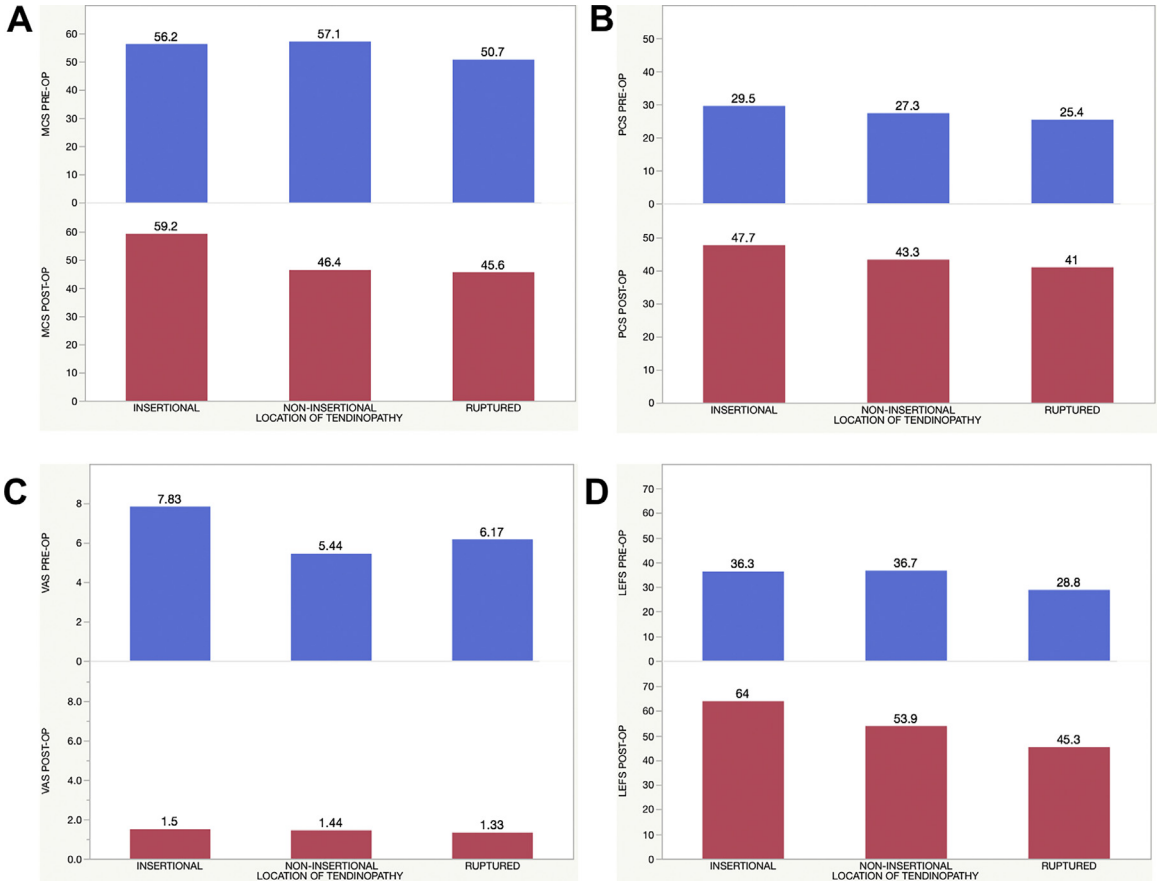

Fig. 2. Graphical plots of mean values for standardized questionnaires in patients with different types of Achilles tendinopathy (insertional, non-insertional and with history of prior rupture). (A) SF-36 mental component summary (MCS); (B) SF-36 physical component summary (PCS); visual analogue score (VAS) for pain; and lower extremity functional scale (LEFS).

Moreover, we did not have an accurate and objective surrogate evaluation of ankle and lesser toes plantarflexion muscle strength to allow a proper comparison with the non-involved side.

In conclusion, the use of the FDL tendon transfer represents a successful and safe operative treatment option for patients with chronic Achilles tendon disorders, including chronic tendinopathy and spontaneous ruptures. This technique can be considered as an alternative for the more traditionally used FHL tendon transfer, especially in the more active and young population, since it has comparable clinical and functional outcomes, with low incidence of complications, donor site morbidity and gait disturbance issues. It can also be used as a revision technique in the treatment of failed FHL reconstructions. Comparative studies focusing on the clinical outcomes of FHL and FDL transfer are warranted.

Conflict of interest

Author Dr. Lew Schon reports conflicts of interest not related directly to this study but has provided paid consultancy for orthobiologics: Spinesmith, Zimmer Biomet, Wright Medical. The authors declare that they have no conflict of interest related to this manuscript.

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Ethical approval

This study was approved by the ethical committee of our Institution.

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