Article

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Do Patients With Functional Hallux Limitus Have a Low-Lying or Bulky FHL Muscle Belly?

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Abstract

Background: Functional hallux limitus (FHLim) refers to a limitation of hallux dorsiflexion when the first metatarsal head is under load, whereas physiologic dorsiflexion is measured in the unloaded condition. Limited excursion of the flexor hallucis longus (FHL) in the retrotalar pulley has been identified as a possible cause of FHLim. A low-lying or bulky FHL muscle belly could be the cause of this limitation. However, to date, there are no published data regarding the association between clinical and anatomical findings. The purpose of this anatomical study is to correlate the presence of FHLim and objective morphologic findings through magnetic resonance imaging (MRI).
Methods: Twenty-six patients (27 feet) were included in this observational study. They were divided into 2 groups, based on positive and negative Stretch Tests. In both groups, we measured on MRI the distance from the most inferior part of the FHL muscle belly and the retrotalar pulley as well as the cross-sectional area of the muscle belly 20, 30, and 40 mm proximal to the retrotalar pulley.
Results: Eighteen patients had a positive Stretch Test and 9 patients had a negative Stretch Test. The mean distance between the most inferior part of the FHL muscle belly and the retrotalar pulley was 6.0 ± 6.4 mm for the positive group and 11.8 ± 9.4 mm for the negative group ($P = .039$). The mean cross section of the muscle measured at 20, 30, and 40 mm from the pulley were 190 ± 90, 300 ± 112, and 395 ± 123 mm^2 for the positive group and 98 ± 44, 206 ± 72, and 294 ± 61 mm^2 for the negative group (P values .005, .019, and .017).
Conclusion: Based on these findings, we can conclude that patients with FHLim do have a low-lying FHL muscle belly causing limited excursion in the retrotalar pulley. However, the mean volume of the muscle belly was comparable in both groups, and therefore bulkiness was not found to be a contributing factor.

Level of Evidence: Level III, observational study.

Keywords: functional hallux limitus, flexor hallucis longus Stretch Test, low-lying FHL muscle belly, bulky FHL muscle belly

Introduction

Functional hallux limitus (FHLim) is a condition first defined by Laird[4] whereby there is a loss of metatarsophalangeal joint (MTPJ) extension when the first metatarsal head is subjected to ground reaction force, as occurs during the terminal stance phase of gait. However, these patients have physiological dorsiflexion of the hallux under unloaded conditions.[1] The term *functional* is used because it is hypothesized that this form of limitation has a dynamic,

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extra-articular etiology, whereas in hallux rigidus there is a structural etiology within the first metatarsophalangeal joint (MTPJ1) mostly in the form of degenerative changes leading to a mechanical block.[10]

According to Danenberg in his sagittal plane facilitation theory, the lack of dorsiflexion of the first MTPJ has detrimental effect on the smooth transference of body weight during the propulsive phase of gait, leading to failure of the auto supportive mechanism and also disruption in the structural integrity of the foot itself.[1] The various compensatory mechanisms that kick in due to FHLim include lateral deviation of the center of pressure, increased pronation at the midtarsal and subtalar joints, abductory twist, early heel-off (lack of ankle dorsiflexion), and lack of full hip and knee extension.[2]

The compensatory mechanism results in symptoms not only in the region of the foot and ankle but also the knee, hip, and back. Some patients have symptoms including pain in the path of the flexor hallucis longus (FHL) tendon, over the base of the big toe, the sesamoids, and behind the medial malleolus. However, it is important to be aware that FHLim can also be totally asymptomatic.[10] The most prevalent sign associated with FHLim is a pinch callus.[8]

The limited excursion of the FHL in the fibro-osseous tunnel posterior to the talus also known as the retrotalar pulley has been established as a possible cause of FHLim and sagittal plane blockade.[3,5,10]

This pulley is around 15 mm in length and 1.5 mm in thickness. It runs between the posterolateral and posteromedial tubercles of the talus.[9] It guides the flexor hallucis longus tendon (FHLT) distally.[6]

Forced dorsiflexion at the first MTP joint is common in athletes in a variety of sports including ballet dancers, and this can lead to overuse injury to the FHL tendon. Any damage to the FHL tendon can result in the alteration of the tendon structure and function, causing it to be entrapped in the retrotalar pulley.[7]

Several tests exist to diagnose FHLim. These are the Dananberg test, Jack test, and the Buell test. The Dananberg test measures proximal phalanx dorsiflexion of the big toe while the first metatarsal head is stabilized by the examiner avoiding plantarflexion (simulated weightbearing position). The purpose of the Jack test (Hubscher maneuver) is to assess the functionality of the windlass mechanism and stability of the arch of the foot. It has also been used to measure functional hallux limitus. Jack test measures proximal phalanx dorsiflexion of the big toe while the patient is weightbearing (the ground itself acting to prevent plantarflexion of the first metatarsal). The Buell test measures proximal phalanx dorsiflexion of the big toe without restriction of the movement of the first metatarsal head, hence simulating the nonweightbearing state. All these 3 tests are measures for functional hallux limitus. The Jack test is a weightbearing test, the Dananberg test is a simulated weightbearing test, and the Buell test is a nonweightbearing test. The normal value for the Jack test is 37 to 40 degrees of dorsiflexion; for the Dananberg test, it is 60 to 75 degrees (abnormal if $<$12 degrees); and for the Buell test, 40 to 82 degrees. Less than 40 degrees of dorsiflexion during the Buell test indicates structural limitation to the hallux movement due to hallux rigidus.[8]

A recent study identified the Dananberg and Jack tests to be reliable for assessing FHLim regardless of the pathogenesis.[8]

To our knowledge, the only available test to identify FHLim caused by FHL limited excursion in the retrotalar pulley is the Stretch Test.[5] This test was first described by Michelson and Dunn,[5] and a positive test for restricted FHL excursion consisted of the patient having discomfort in the first MTP joint during range of motion when the ankle was moderately dorsiflexed and the first metatarsal stabilized, or by a decrease in first MTP joint dorsiflexion to $<$20 degrees. It was then simplified by Vallotton et al in 3 steps. The first step is to check the full range of motion of the MTPJ1 while the ankle is in plantarflexion. Normally the big toe can be dorsiflexed beyond neutral. If there is any limitation to the dorsiflexion of the hallux while the ankle is in plantarflexion, then the test becomes inconclusive. The second step is to place the ankle firmly in the maximally dorsiflexed position. If there is any equinus deformity or the ankle is unable to be dorsiflexed beyond neutral, the test is also inconclusive. The third step is to dorsiflex the hallux beyond neutral. If it is possible then the Stretch Test is negative; if there is no dorsiflexion possible, the Stretch Test becomes positive (as shown in the picture).[10]

Up to now, there is no evidence on the association between clinical and morphologic findings, that is, a positive Stretch Test and a low-lying or bulky muscle belly. This study aims to determine the role of FHL anatomy with respect to its retrotalar pulley, comparing these findings in patients with positive and negative Stretch Tests.

To establish this, we did an observational magnetic resonance imaging (MRI) study looking at (1) the distance between the retrotalar pulley and the most inferior part of the FHL muscle belly, and (2) the cross-sectional area of the muscle belly 2, 3, and 4 cm proximal to the retrotalar pulley in both positive and negative Stretch Test groups.

Materials and Methods

Participants

We recruited patients attending our foot and ankle center over a 10-month period from October 2019 and July 2020, who presented themselves with any given foot or ankle pathology.

The inclusion criteria were patients older than 18 who presented themselves in our outpatient clinic. There were

Table 1. Various pathologies in the study group.

Pathology	Frequency
Achilles tendonitis	3
Ankle laxity	1
Ankle sprain	4
Calcaneum cyst	1
Flatfoot	1
Nonunion of the fifth MTB	1
Osteochondral lesion of talus	3
Os trigonum	1
Plantar fasciitis	3
Plantar fibromatosis	1
Pigmented villonodular synovitis	1
Spring ligament sprain	1
Hip arthritis	1
Midfoot pain	1
Normal MRI	2
Peroneal tendon rupture	1
Peroneal tendon subluxation	1
Total	27

Abbreviations: MRI, magnetic resonance imaging; MTB, metatarsal bone.

multiple foot and ankle pathologies in the study group, and we have listed them in Table 1.

Exclusion criteria were arthritic changes in the ankle, the hindfoot, or the forefoot such as hallux rigidus and any restriction of the hallux motion in the nonweight-bearing state. We also excluded patients who had any pathologic condition, previous surgery, or trauma that could have affected the flexor hallucis tendon structure or motion. Patients with hallux valgus were not included in the study as the sesamoids are displaced, and dorsiflexion of the great toe does not maximally stretch the FHL tendon, which may result in a false-negative Stretch Test. Also excluded from the study were patients with flatfoot. Flattening of the arch is postulated to increase the tension in the plantar fascia, thereby negatively influencing the windlass mechanism and also contributing to FHLim.[2]

Procedure

We used the FHL Stretch Test to check the amplitude of motion of the big toe in dorsiflexion. This test was performed with the patient supine and knee extended. We followed the method as described by Vallotton et al. The Stretch Test was done with the knee straight as we are trying to reproduce the position of the knee and ankle during the terminal stance phase of gait cycle where the knee is extended and ankle dorsiflexed. If there was any equinus deformity (including due to Achilles contracture or gastrocnemius tightness), the patient was excluded from the study as we did not want limitation in ankle dorsiflexion to influence our results. The ankle was initially allowed to be in the resting plantarflexed position, and the mobility of MTPJ1 was determined. At this point, if there was any limitation to the MTPJ1 dorsiflexion, the patient was excluded from the study. Next, the ankle was placed in maximum dorsiflexion by placing the palm of the examiner's hand beneath the first metatarsophalangeal head while supporting the bent elbow against the iliac crest. Then the MTPJ1 was maximally dorsiflexed. If the toe is able to be dorsiflexed even a few degrees beyond neutral then the test is negative, but if no dorsiflexion is possible or the toe goes into plantarflexion then the test is positive.[10]

A single fellowship-trained orthopaedic surgeon specializing in foot and ankle surgery performed the Stretch Test (Figure 1).

MRI

For all patients, MRIs were done with the ankle in 90° of dorsiflexion. We standardized the position of the foot and ankle by placing it in a prefabricated mold. The prefabricated mold is a thermoplastic splint that prevents the ankle from going into the resting equinus state. This position was repeated in all patients undergoing the MRI in our study, and the surgeon ensured that the position of the foot and ankle were all the same for all the patients. The position of the great toe was not controlled, that is, not splinted into a specific position but rather was allowed to be in its natural relaxed state.

By using a T2-weighted 3D-SPACE MRI, images were reformatted in the axial and sagittal planes that allowed a 360° reconstruction. This was possible because the pixel size is almost isometric with values of $0.63 \times 0.63 \times 0.7$.

Two measurements were derived from the MRI:

1. Distance from the most inferior part of the FHL muscle belly to the retrotalar pulley in the reconstructed sagittal plane.

In order to obtain this measurement, we identified the midpoint of the retrotalar pulley on the axial plane (Figure 2). From this point, we switched to the sagittal cut and the image was rotated around the coronal plane so that it lies in the same longitudinal plane as the FHLT (Figure 3). In this reformatted sagittal plane, we identified the most inferior part of the FHL muscle belly. We then rotated all around this point in the axial plane to visualize the lowest part of the FHL muscle belly (Figure 4). Once this was done, we measured the exact distance from the center of the retrotalar pulley to this muscle belly.

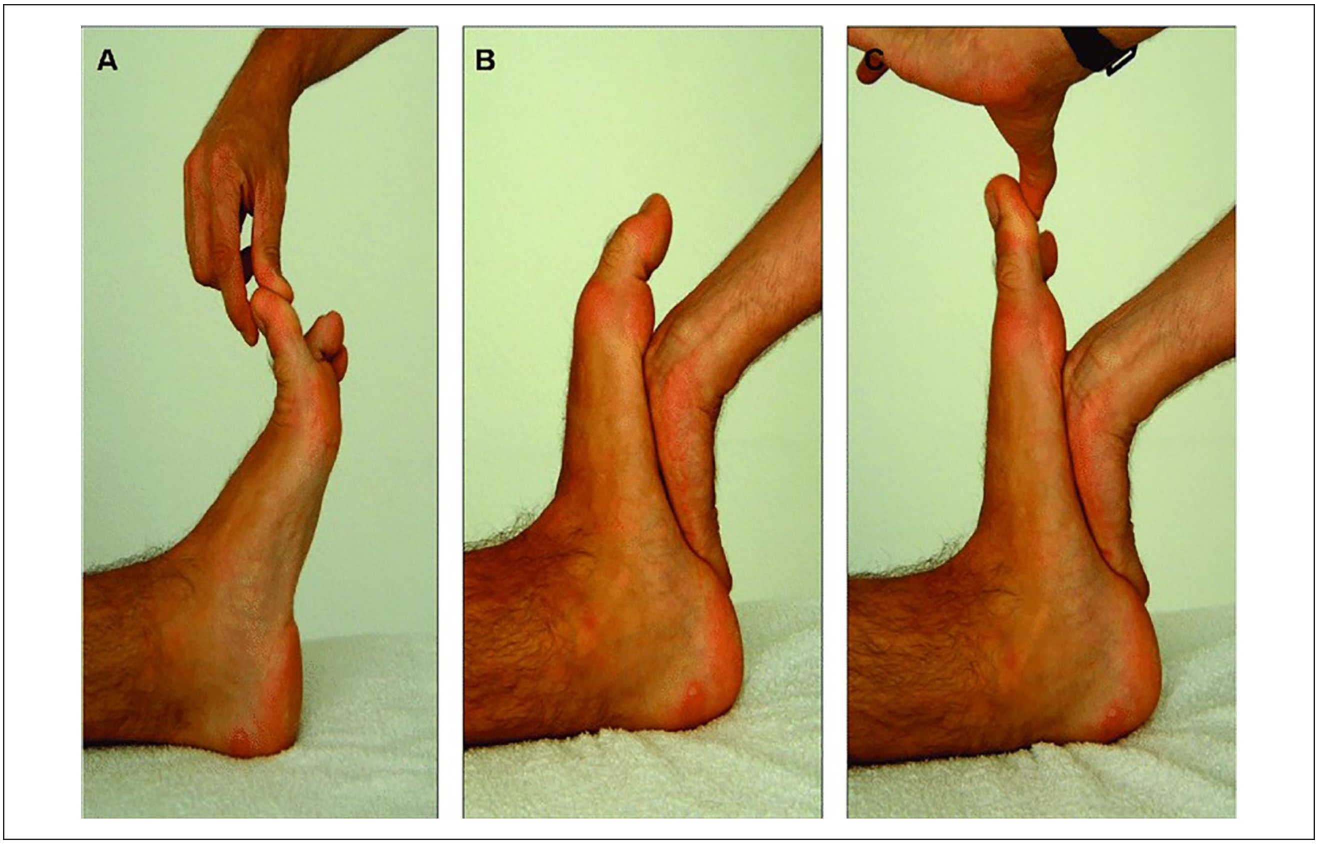

Figure 1. FHL Stretch Test (A) Maximum passive big toe dorsiflexion when ankle is in neutral plantarflexion, (B) Maximum passive dorsiflexion of the ankle joint, (C) Maximum passive big toe dorsiflexion when ankle in maximal dorsiflexion.
Source: Courtesy Dr J. Valloton.

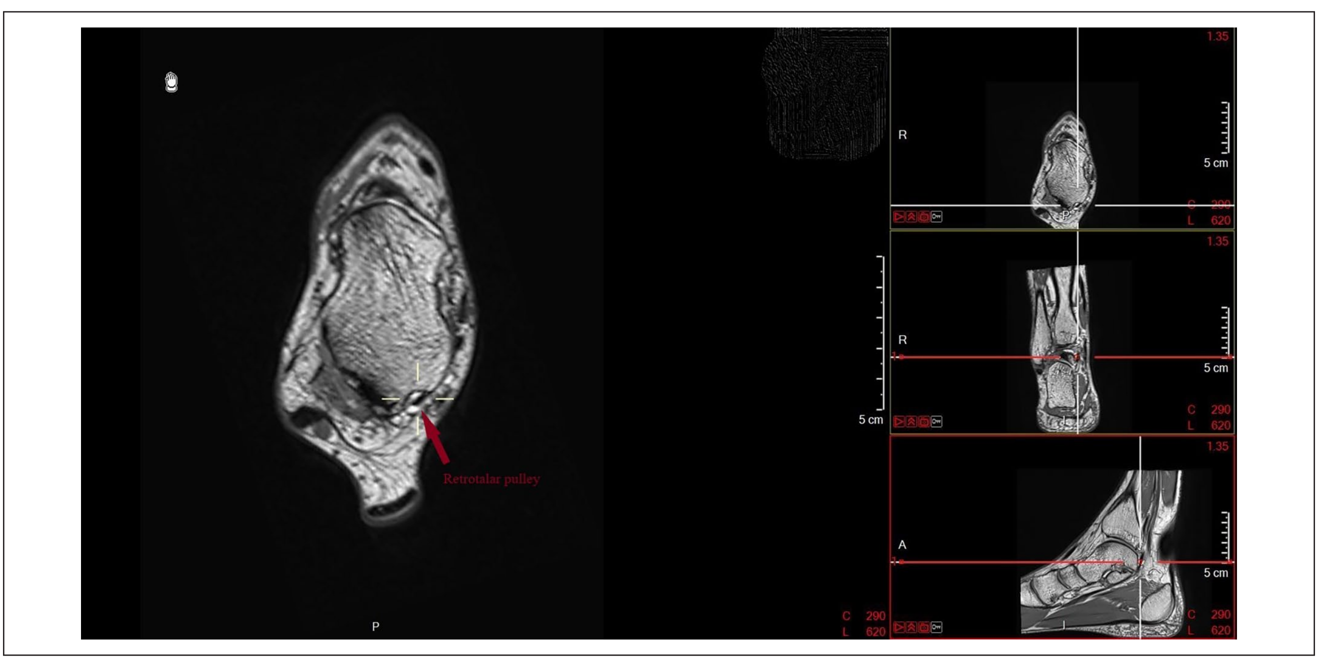

Figure 2. Identification of the retrotalar pulley on the axial plane.

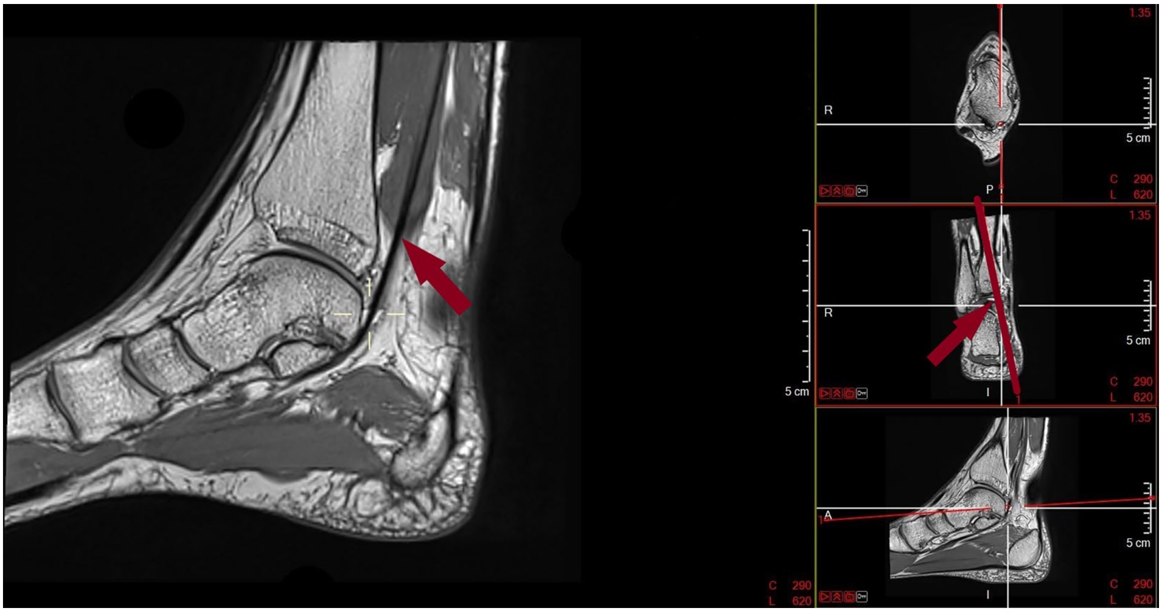

Figure 3. The sagittal cut at the retrotalar pulley with the image rotated around the coronal plane so that it lies in the flexor hallucis longus muscle plane.

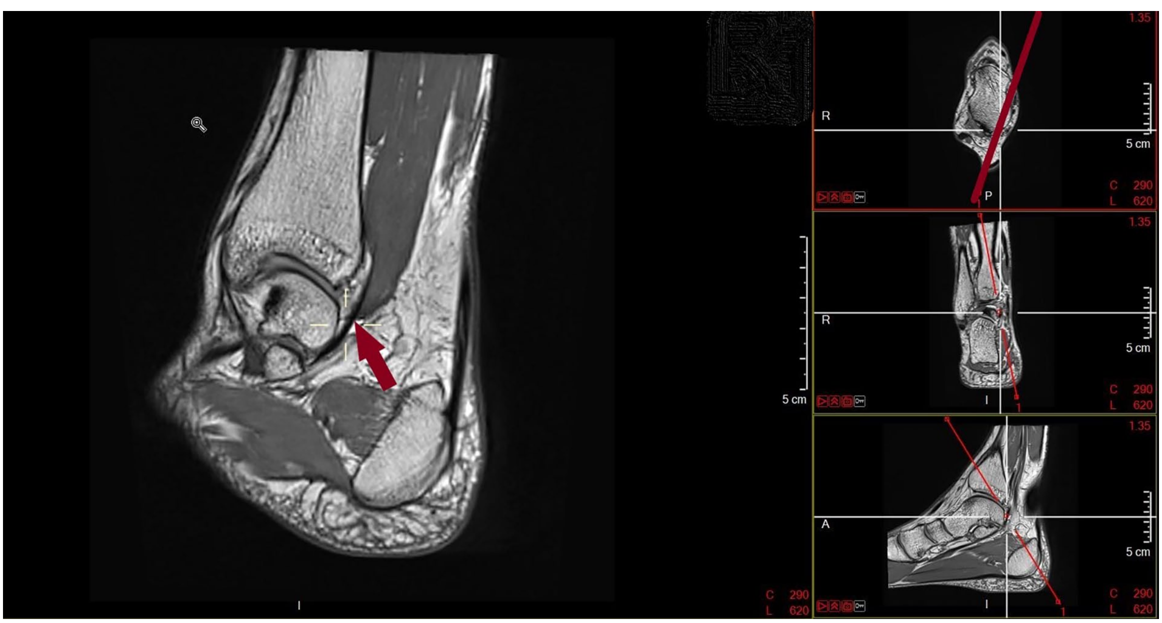

Figure 4. Image rotated in the axial plane to visualize the lowest part of flexor hallucis longus muscle belly.

2. Cross-sectional area of the FHL muscle belly proximal to the retrotalar pulley in the reconstructed axial plane.

For this part, we identified 3 points that were 20, 30, and 40 mm proximal to the center of the retrotalar pulley on the sagittal plane (Figures 5-7).

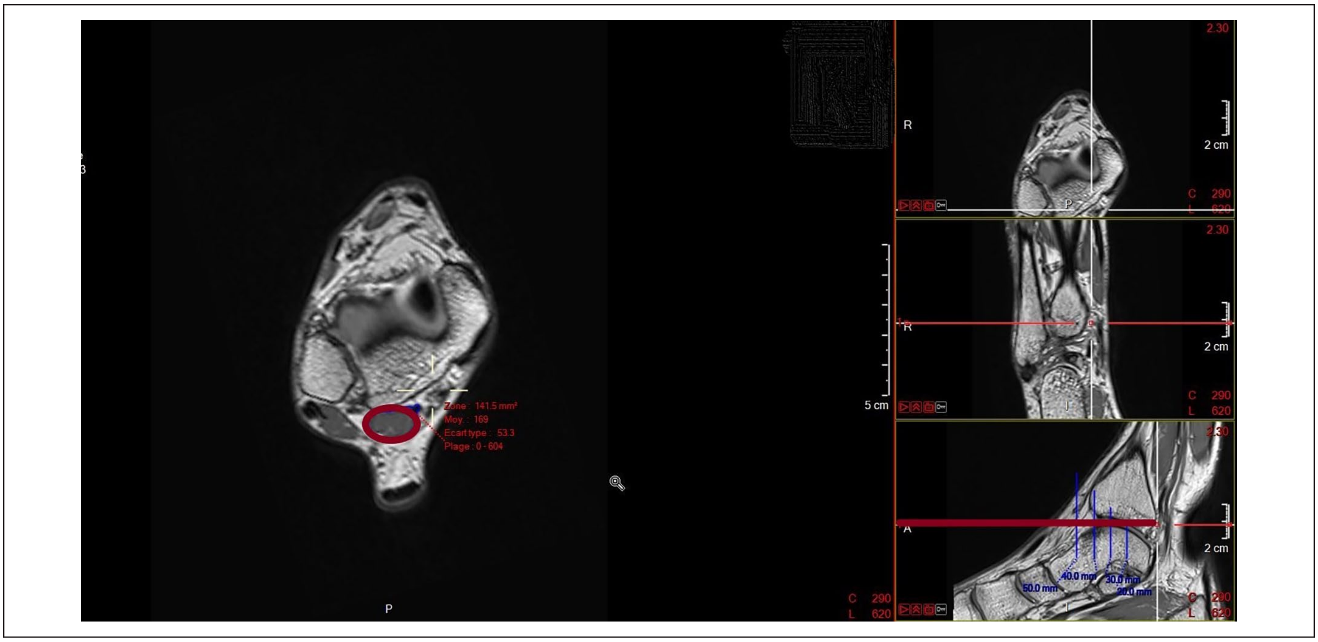

Figure 5. Cross-sectional area 20 mm proximal from the center of the retrotalar pulley.

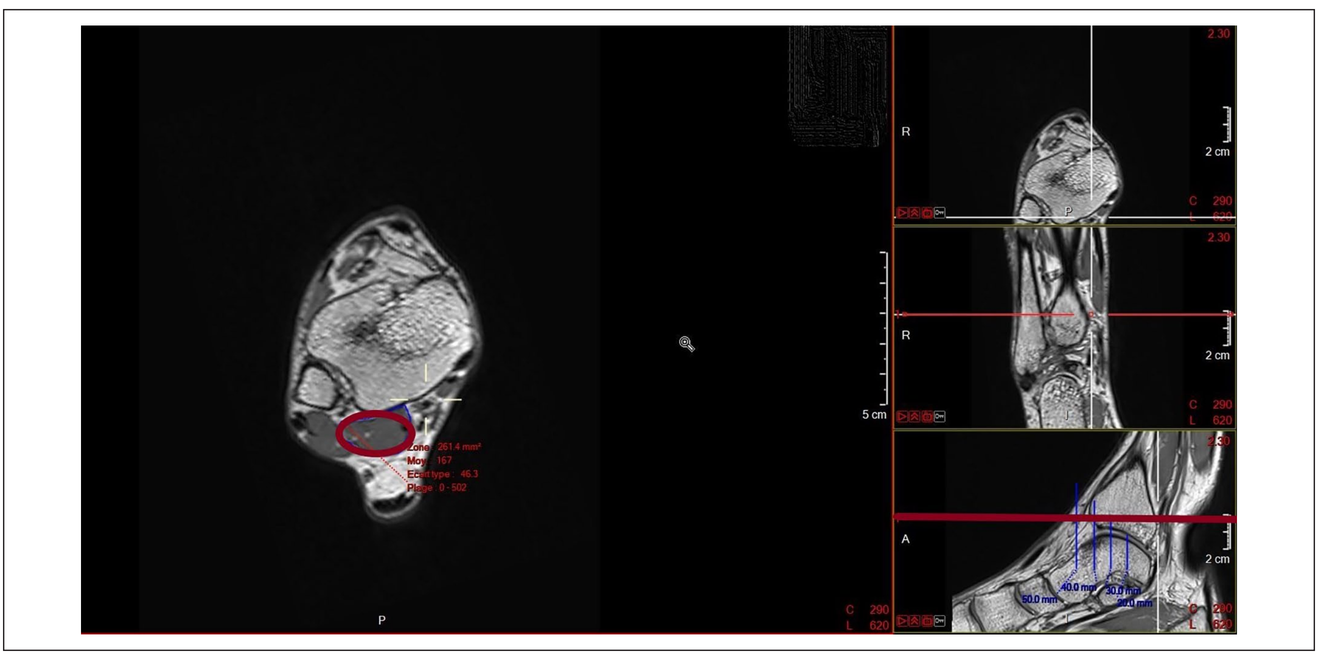

Figure 6. Cross-sectional area 30 mm proximal from the center of the retrotalar pulley.

At these reference points, we then switched to the axial plane to measure the cross-sectional area of the FHL muscle belly.

All these measurements were done by the same surgeon.

Analysis

Statistical analysis was performed using *t* tests for continuous variables.

We present the results as mean ± SD. A P value of $<.05$ was deemed to be significant.

Results

Twenty-six patients (27 feet) were included in the study. The mean age of the patients was 45 years (range, 24-61 years), with 12 female and 14 male patients.

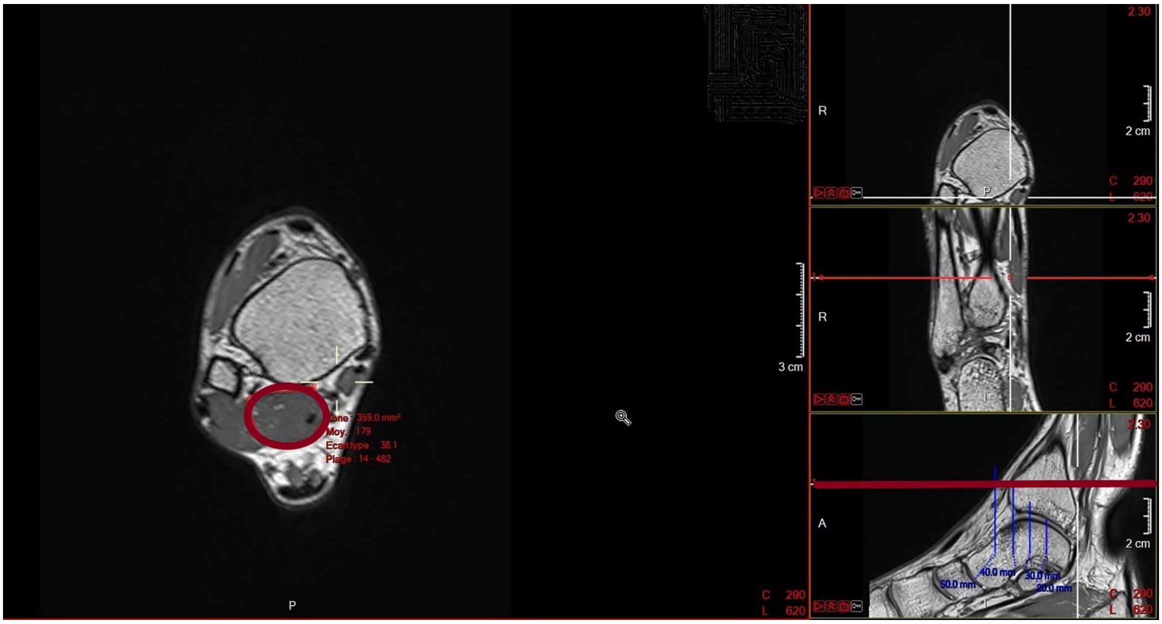

Figure 7. Cross-sectional area 40 mm proximal from the center of the retrotalar pulley.

Table 2. Patient Characteristics and Outcome.[a]

Parameters	Positive Stretch Test (n = 18)	Negative Stretch Test (n = 9)	*P* Value
Age, y	44.3 ± 9.6	42.8 ± 11.3	.721
No. of males/females	10:8	4:5	.603
No. of left/right feet involved	11:7	4:5	.431
Distance of pulley to muscle belly (mm)	6.0 ± 6.4	11.8 ± 9.4	.039
Surface area at 2 cm (mm^2)	190 ± 90	98 ± 44	.005
Surface area at 3 cm (mm^2)	300 ± 112	206 ± 72	.019
Surface area at 4 cm (mm^2)	395 ± 123	294 ± 61	.017

[a]Data are presented as mean ± SD or no. of patients.

The positive Stretch Test group consisted of 18 patients whereas the negative group had 9 patients. None of the patients had any symptoms related to the FHL tendon.

The two groups were comparable in terms of age (P = .721), sex (P = .603), and limb involved (right or left) (P = .431).

In the positive Stretch Test group, the distance from the inferior part of the FHL muscle belly to the retrotalar pulley was 6.0 ± 6.4 mm, whereas in the negative group it was 11.8 ± 9.4 mm. This was statistically different (P = .039).

The mean cross-sectional areas of the FHL muscle belly measured proximally at 20, 30, and 40 mm from the pulley were 190 ± 90, 300 ± 112, and 395 ± 123 mm^2 for the positive group and 98 ± 44, 206 ± 72, and 294 ± 61 mm^2 for the negative group, and they were significantly different (P values .005, .019, and .017) (Table 2).

Discussion

The purpose of this study was to find out if patients with FHLim (positive stretch test) have a low-lying muscle belly or bulky FHL muscle. Our research hypothesis was that the lower and bulkier the FHL muscle belly, the higher the chance of limited excursion at the retrotalar pulley. We tested this hypothesis by digitally measuring the distance of the lowest point of the muscle belly to the center of the retrotalar pulley on MRIs. We also measured the cross-sectional area of the muscle belly at various distances from the pulley. To our knowledge, this is the first study that has evaluated the relationship between a positive Stretch Test and a low-lying FHL muscle belly identified through MRI. We did it to try to explain the etiology of a physical examination finding and not to relate it to a pathology or a symptom.

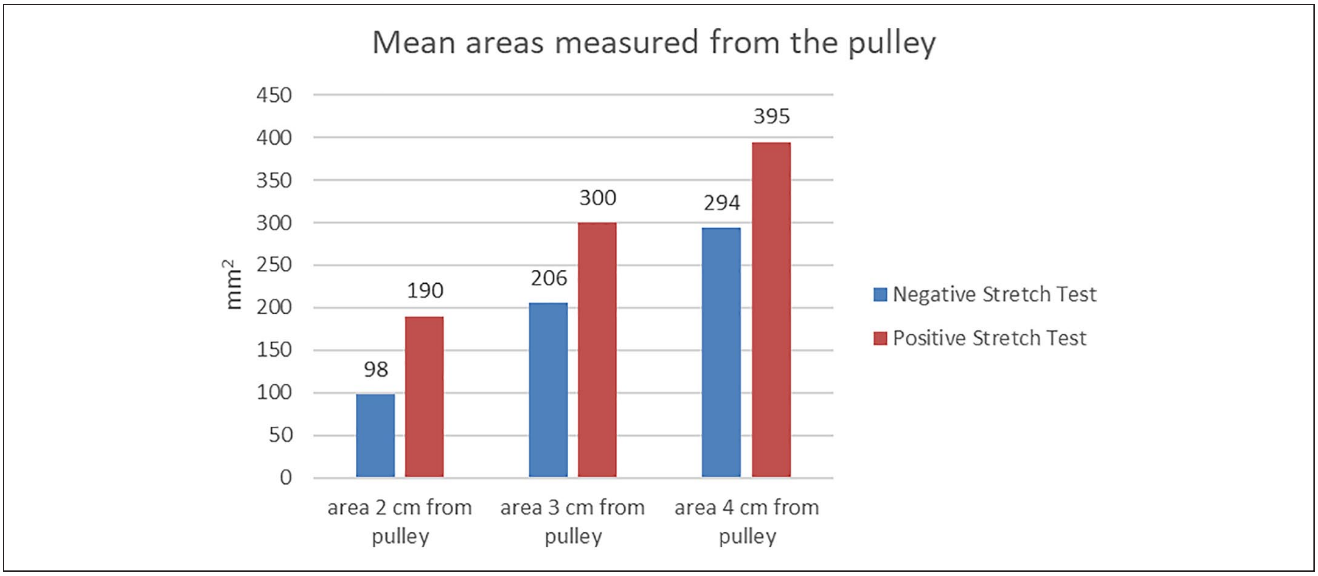

Figure 8. Histogram showing increment in flexor hallucis longus muscle belly surface area as we progress proximally from the retrotalar pulley.

We discovered from our study that a low-lying FHL muscle belly correlates with a positive Stretch Test and hence could cause FHLim. Eighteen patients who had a positive Stretch Test had a low-lying muscle belly whereas 9 patients with a negative Stretch Test had a more proximally lying muscle belly. This shows that a low-lying FHL muscle belly significantly contributes to a limited excursion at the retrotalar pulley. This is in line with the findings by Tzioupis et al, who recorded dynamic images acquired during posterior ankle arthroscopy. They were able to observe that in some patients, the distal part of the muscle belly extended further down and was forced through the retrotalar pulley.[9]

We also noticed that a bulky FHL muscle belly does not necessarily correlate with a positive Stretch Test and hence cannot be systematically linked to FHLim. This was supported by incremental measurements of the muscle belly surface area from distal to proximal. Measurements showed that the surface area progression was similar in both groups (Figure 8). This puts into question the findings by Sammarco and Cooper[7] who suggested FHL tendon gliding restriction during big toe dorsiflexion may be due to bulky muscle belly. In our study, the only relevant value that was found to be associated with FHLim was the distance between the pulley and the most inferior part of the muscle belly and not the size of the muscle belly.

As a technical tip for further studies, we recommend measuring the distance between the inferior part of the FHL muscle belly and the retrotalar pulley on the exact plane of the FHL muscle, which is obliquely orientated. This is only possible with an isometrical MRI sequence that allows for 3D reconstruction; this is not the case with classical MRIs.

A limitation of this study was the small sample size as well as an unequal number of patients in each group. In fact, the positive Stretch Test group had twice the number of patients. This was unavoidable as the prevalence of this condition is indeed very high as shown by Payne et al[6] in his study, where 53 of 86 asymptomatic feet had FHLim.

Ideally, we would have liked to measure the surface area of the retrotalar tunnel and analyze its association with the FHL muscle belly. However, because of technical limitations, it was not possible as the pulley could not be clearly visualized on all patients despite high-quality 3-tesla MRIs.

Besides these limitations, we believe that the results from this study will help clinicians to better understand the connection between a positive Stretch Test and the anatomy behind it. We hope that the study will serve as a catalyst for future research on FHLim.

Conclusion

Based on these findings, we can conclude that patients with FHLim do have a low-lying FHL muscle belly causing limited excursion in the retrotalar pulley. However, a bulky FHL muscle belly does not correlate with FHLim.

Ethical Approval

Ethical approval was not sought for the present study as it was a noninterventional observational study. The stretch test was done routinely in the clinic after informed consent as part of a general foot and ankle examination. MRI investigation was not ordered specifically for this study but as part of a necessary clinical investigation of foot pathologies. Study data were collected and analysed retrospectively and anonymously. Patient confidentiality was not breached at any point in the study.

Declaration of Conflicting Interests

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References

1. Dananberg HJ. Functional hallux limitus and its relationship to gait efficiency. *J Am Podiatr Med Assoc*. 1986;76(11):648-652.
2. Durrant B, Chockalingam N. Functional hallux limitus: a review. *J Am Podiatr Med Assoc*. 2009;99(3):236-243. doi:10.7547/0980236
3. Hamilton WG. Foot and ankle injuries in dancers. *Clin Sports Med*. 1988;7(1):143-173.
4. Laird PO. Functional hallux limitus. *Ill Podiatr*. 1972;9:4.
5. Michelson J, Dunn L. Tenosynovitis of the flexor hallucis longus: a clinical study of the spectrum of presentation and treatment. *Foot Ankle Int*. 2005;26(4):291-303.
6. Payne C, Chuter V, Miller K. Sensitivity and specificity of the functional hallux limitus test to predict foot function. *J Am Podiatr Med Assoc*. 2002;92(5):269-271.
7. Sammarco GJ, Cooper PS. Flexor hallucis longus tendon injury in dancers and nondancers. *Foot Ankle Int*. 1998;19(6):356-362. doi:10.1177/107110079801900603
8. Sánchez-Gómez R, Becerro-de-Bengoa-Vallejo R, Losa-Iglesias ME, et al. Reliability study of diagnostic tests for functional hallux limitus. *Foot Ankle Int*. 2020;41(4):457-462.
9. Tzioupis C, Oliveto A, Grabherr S, Vallotton J, Riederer BM. Identification of the retrotalar pulley of the flexor hallucis longus tendon. *J Anat*. 2019;235(4):757-764.
10. Vallotton J, Echeverri S, Dobbelaere-Nicolas V. Functional hallux limitus or rigidus caused by a tenodesis effect at the retrotalar pulley: description of the functional stretch test and the simple hoover cord maneuver that releases this tenodesis. *J Am Podiatr Med Assoc*. 2010;100(3):220-229.