Flexor Hallucis Longus Hypertrophy Secondary to Achilles Tendon Tendinopathy: An MRI-based Case-Control Study

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Abstract

Background: The purpose of this study was to outline indirect signs of advanced Achilles tendinopathy on magnetic resonance imaging (MRI) and develop a potential tool that could aid in surgical decision-making.

Methods: Magnetic resonance imaging (MRI) scans of Achilles tendon were analyzed retrospectively in two consecutive cohorts. Control group consisted of patients that had an MRI due to other reasons and no signs of tendinopathy. Two parameters from two muscle bellies were measured and compared on axial MRI scans 4 to 5 cm above the ankle joint line at the level of greatest thickness: area and diameter of the triceps surae (TS) and of the flexor hallucis longus (FHL). Interobserver agreement was analyzed. A receiver operating characteristic (ROC) curve was created for both quotients to assess potential cut-off points.

Results: A total of 60 patients for each study group were included. The ratios for area and for diameter showed significant higher values for FHL in the tendinopathy group ($p<0.001$). There was strong to very strong interobserver agreement ($rho=0.744$). A diameter ratio FHL/TS of 2.0 or higher had a sensitivity of 49% and specificity of 90% for concomitant Achilles tendinopathy.

Conclusion: In our patient cohort, flexor hallucis longus hypertrophy was observed even before a tendon transfer was employed as a possible compensatory mechanism for Achilles tendon tendinopathy. Using the tool described in this study, measuring a value of 2.0 or higher on an axial MRI, may be indicative as an indirect sign of functional deterioration of the Achilles tendon.

Background

Chronic Achilles tendinopathy represents a common disease that can affect professional athletes(1) and also people engaging occasionally in sports or even having a sedentary lifestyle.(2) In 2011, its incidence in a Dutch population was described as 2 per 1000 patients registered by a general practitioner (GP).(3) In an histological study, 34% of the Achilles tendon specimens of spontaneously ruptured tendons were showing signs of tendinopathy, suggesting that the acute lesions also have a predisposing degeneration.(4) This further supports the importance of timely diagnosing and delivering the appropriate management.

First line of treatment is usually conservative and may take up months to demonstrate effectiveness. This includes reduction of load, stretching as well as eccentric muscle strengthening and may lead to a favorable outcome in 71% of the cases.(5) However, as many as 25% of patients fail conservative therapy and require surgery.(6) Surgical procedures, mostly consisting debridement with direct repair, are considered when conservative treatment is not successful after an average period of 3 to 6 months.(7, 8) A variety of surgical options have been described without a definitive consensus on the best technique.(9)

If there is advanced damage of the tendon(6), a tendon transfer is a recommended option. (10-13) One of the most widely used is the flexor hallucis longus (FHL) transfer.(14) Evidence demonstrated a hypertrophy of the FHL after performing a tendon transfer.(15, 16)

In our practice, there was a clinical observation that the FHL hypertrophy may even occur preoperatively in cases with severe Achilles tendinopathy as a compensatory mechanism. The purpose of the current study was to find out whether such an observation is true or not. A secondary scope was to build an objective reproducible tool that would aid in the surgical decision-making when assessing patients with chronic Achilles tendinopathy.

Methods

MRI imaging over a continuous period between 2016 and 2017 that assessed the calf region and included the Achilles tendon were extracted from the local database. Only imaging of sufficient quality that included sagittal and axial views (T1 as well as T2 weighted/ STIR (short tau inversion recovery)/ with and without fat suppression) were included. All patients that were included signed a written consent form. The study was approved by our institutional ethical review board and by the local Ethics Commission (BASEC Nr. 2018-00098). The study was carried out in accordance with the World Medical Association Declaration of Helsinki.(17)

Patient selection

Inclusion criteria for the tendinopathy group were patients that exhibited radiographic signs of Achilles tendon tendinopathy as defined by previous studies,(18, 19) which included combinations of the following: intratendinous signal alterations, interstitial or insertional tears, peritendinous edema, loss of the physiological concave shape of the tendon, irregular mucoid deposition, intratendinous multifocal speckled appearance with changes in volume.

The control group included subjects that presented without any complaints regarding the Achilles function and presented a normal radiographic morphology of the Achilles tendon on MRI. Exclusion criteria in both groups were relevant morphologic changes of the upper ankle joint, the hindfoot or the calf muscles as well as history of relevant previous surgery or injury of the lower limb.

Radiographic Measurement Strategy

Axial MRI scans were analyzed on a level 4 to 5 cm above the ankle joint line at the level of greatest thickness for each muscle belly. This height was chosen as it was consistently representative of a good portion of muscle belly for both FHL and Triceps surae. A sagittal view was then used to verify the height **(Fig. 1)**. The MRI slice thickness was 6 mm. Next, for measurement of the diameter of the TS, a perpendicular line was drawn to the frontal plane through the midline of the muscle belly. For the FHL muscle, we measured the distance from the medial corner of the fibula to the posteromedial corner of the FHL muscle (**Fig. 2**). This last spot can be defined very easily, as the neurovascular bundle runs exactly at

the posteromedial corner of the FHL. Measurements were made in both groups by two independent investigators (**Fig 3**). Next, quotients of the area (FHL/TS) and quotients of the diameter (FHL/TS) were calculated.

Statistical Analysis

Data was mainly non-normally distributed. Medians and interquartile ranges (IQR) are given. Spearman correlation analysis tested for interobserver agreement. The Wilcoxon rank sum test was used to compare measurements between groups. A logistic regression model was fitted to account for the potential confounder age, sex, and side. A receiver operating characteristic (ROC) curve was created for both quotients to assess potential cut-off points. A post hoc power analysis using a test comparing two independent means yielded a sufficient power (power=0.999 for the quotient of the diameter of FHL devided by TS). Stata/IC (version 13.1; StataCorp LP, College Station, TX, USA) was used.

Results

Demographics of the study participants are represented in **Table 1**. The mean height of measurement was 4.5cm above the ankle joint in both groups.

Table 1. Demographics of continuous and categorical data (n=120)

	Tendinopathy (median [IQR])		
Variable	Yes (n=60)	No (n=60)	P-value
Age (y)	60 (16)	38 (31)	<0.001 (Wilcoxon rank sum test)
Gender			0.006 (Chi squared test)
Females	24 (40%)	39 (65%)	
Males	36 (60%)	21 (35%)	
Side			0.144 (Chi squared test)
Right	34 (57%)	26 (43%)	
Left	26 (43%)	34 (57%)	

Abbreviations: IQR (interquartile range), y (years)

The ratio FHL/TS regarding the diameter showed significantly higher values in the tendinopathy group than the control group, p<0.001 (median=2.0 [IQR=0.8] vs 1.7 [0.3]) (**Table 2**). Similar results were obtained by calculating the quotient FHL/TS regarding the area, which also showed significantly higher values in the tendinopathy group than in the control group (1.8 [1.3] vs 1.3 [0.7]), p<0.001.

Table 2. Measurements comparing Achilles tendinopathy group to controls

Variable		Tendinopathy (median [IQR])		
		Yes (n=60)	No (n=60)	P-value*
Diameter (mm)				
	FHL	29.5 (6.8)	26.5 (5.0)	<0.001
	TS	14.8 (4.5)	16.0 (3.5)	0.006
	FHL/TS	2.0 (0.8)	1.7 (0.3)	<0.001
Area (mm^2)				
	FHL	545.0 (122.3)	453.3 (131.5)	0.080
	TS	274.5 (182.0)	331.0 (140.5)	<0.001
	FHL/TS	1.8 (1.3)	1.3 (0.7)	<0.001

*Wilcoxon rank sum test
Note: All p-values except area TS remained significant (p<0.05) when a logistic regression model including age, sex, and side was fitted (e.g. for diameter FHL/TS: odds ratio=9.56 [95% confidence interval 2.46-37.22], p=0.001)
Abbreviations: IQR (interquartile range), FHL (flexor hallucis longus), TS (triceps surae)

The interobserver agreement was calculated using the Spearman correlation coefficient (rho). A strong to very strong correlation regarding all measurements was determined: rho 0.60-0.79=strong; 0.80-1.00=very strong (**Table 3**).

In the tendinopathy group there were more males and overall older patients than in the control group (p<0.001). This issue was then addressed in a logistic regression model that fitted results depending on age, gender and affected side.

Table 3. Interobserver agreement

Variable		Rho*	P-value†
Diameter (mm)			
	FHL	0.734	<0.001
	TS	0.921	<0.001
	FHL/TS	0.744	<0.001
Area (mm^2)			
	FHL	0.840	<0.001
	TS	0.896	<0.001
	FHL/TS	0.871	<0.001

*Rho= Spearman-correlation coefficient .
†Spearman-correlation.
Abbreviations: IQR (interquartile range), FHL (flexor hallucis longus), TS (triceps surae)
Note: Strength of correlation: 0.00-0.19=very weak; 0.20-0.39=weak; 0.40-0.59=moderate; 0.60-0.79=strong; 0.80-1.00=very strong

As such, there was still a significant odd's ratio=9.56 [95% confidence interval 2.46-37.22], p=0.001) for an increased ratio of diameter FHL/TS in the tendinopathy group (**Table 2**).

Diameter values together with its calculated quotients (FHL/TS) showed less variation as demonstrated by reduced dispersion on the boxplots (**Fig 4**). Therefore, it was this value that was chosen for the calculation of a potential radiographic tool. For the calculation of a suitable cut-off point for the diameter ratio FHL/TS, a receiver operating characteristic (ROC) analysis was undertaken (**Fig. 5**). A value of 1.6 or above was most sensitive to detect a positive correlation with concomitant tendinopathy with a sensitivity of 83% and specificity of 45%. On the other hand, a value of 2.0 or above, provided a higher specificity of 90%. The latter value was chosen as cut-off margin.

Discussion

This is the first study reporting evidence for FHL hypertrophy that occurs in cases of severe chronic Achilles tendinopathy even before a transfer is employed. Also, the study provides a new objective radiographic tool that might help in the surgical decision-making and should be the base for future studies that will correlate it to clinical outcome.

Previous studies evaluated the reliability of ultrasound examination(20) and compared clinically symptomatic and asymptomatic Achilles tendons which found tendinopathy in 32% of the asymptomatic volunteers.(21) This demonstrates the further need for additional parameters in assessing the functionality of the Achilles tendon. Oksanen et al. found FHL hypertrophy in over 50% of patients after performing a FHL transfer.(15) Similarly was found on postoperative MRI imaging..(15, 22, 23) We believe the hypertrophy may also occur in case of functional deterioration of the triceps surae due to chronic Achilles tendinopathy as a compensatory mechanism.

Another area of need for an additional objective tool is the indication for surgical treatment of a chronic Achilles tendinopathy which is a matter of current debate. Rahm et al. suggested to perform FHL transfer after failure of local debridement, failure of free tendon grafting in case of a tendon defect or advanced fatty infiltration of the TS.(6) A minimal defect of 50% of the tendon was determined as an indication for the need of a tendon transfer by several authors (7, 10, 11, 24) Lin et al.(25) presented an algorithm for the treatment of chronic Achilles tendinopathy based on the presence or absence of stumps on preoperative MRI and the defect gap measured intra-operatively. FHL transfer was considered when the tendon stumps did not have enough integrity.(4) Clinical results were reported to be good to excellent after FHL transfer for multiple pathologies of the Achilles tendon, including extended degenerative

aberrations, partial defects and muscle dysfunction of the TS.(12, 26). Very good ankle plantar flexion strength and an overall clinical success rate of over 70% have been reported. (27-29)

As such, the management for Achilles tendinopathy experiences a variety of treatment strategies and lacks standardized criteria as it depends on subjective considerations of the caretaker.(30) The observed FHL hypertrophy in patients with signs of chronic Achilles tendinopathy provides evidence that further supports its functional synergism and as such, another argument for choosing an FHL transfer. Using the new ratio of diameter TS/FHL, an additional radiographic sign can be potentially employed in the surgical decision-making. Future clinical prospective studies should correlate this parameter to clinical and functional outcome.

Obviously, there are several limitations that should be addressed. The design has a weakness regarding study groups that were not matched on age, BMI or comorbidities, which are possible confounders. This matter was addressed by performing a multiple regression analysis. Another issue is the cross-sectional measurement of the muscle belly at a specific location, that may be not representative of the total muscular volume. Further investigations should explore the possibilities of integration of this new radiographic index into the clinical setting.

Conclusion

In our patient cohort, flexor hallucis longus hypertrophy appeared even before a tendon transfer was employed as a compensatory mechanism for Achilles tendon tendinopathy. Using the tool described in this study, measuring a ratio of FHL/TS diameters of 2.0 or higher, on an axial MRI, may be indicative as an indirect sign of functional deterioration of the tendinopathic Achilles tendon. Future studies should correlate this finding to clinical outcome, which may potentially aid in the surgical decision-making and the employment of a tendon transfer.

Declarations

FUNDING

This research received no specific grant from any funding agency in the public, commercial or not-for-profit sectors.

CONFLICT OF INTEREST

All authors declare that they have no conflict of interest.

ETHICAL APPROVAL

The study was approved by our institutional ethical review board and by the Cantonal Ethics Commission of Zurich (BASEC Nr. 2018-00098). All patients have signed a written consent form.

AVAILABILITY OF DATA AND MATERIALS

Data was deposited safely in a a local repository according to the ethical commission regulations. REDCAP software was used for storage and limited access to the principal investigators.

AUTHORS' CONTRIBUTIONS

All authors have made substantial contributions which are listed in the title page of the submission.

ACKNOWLEDGEMENTS

None to declare.

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Figures

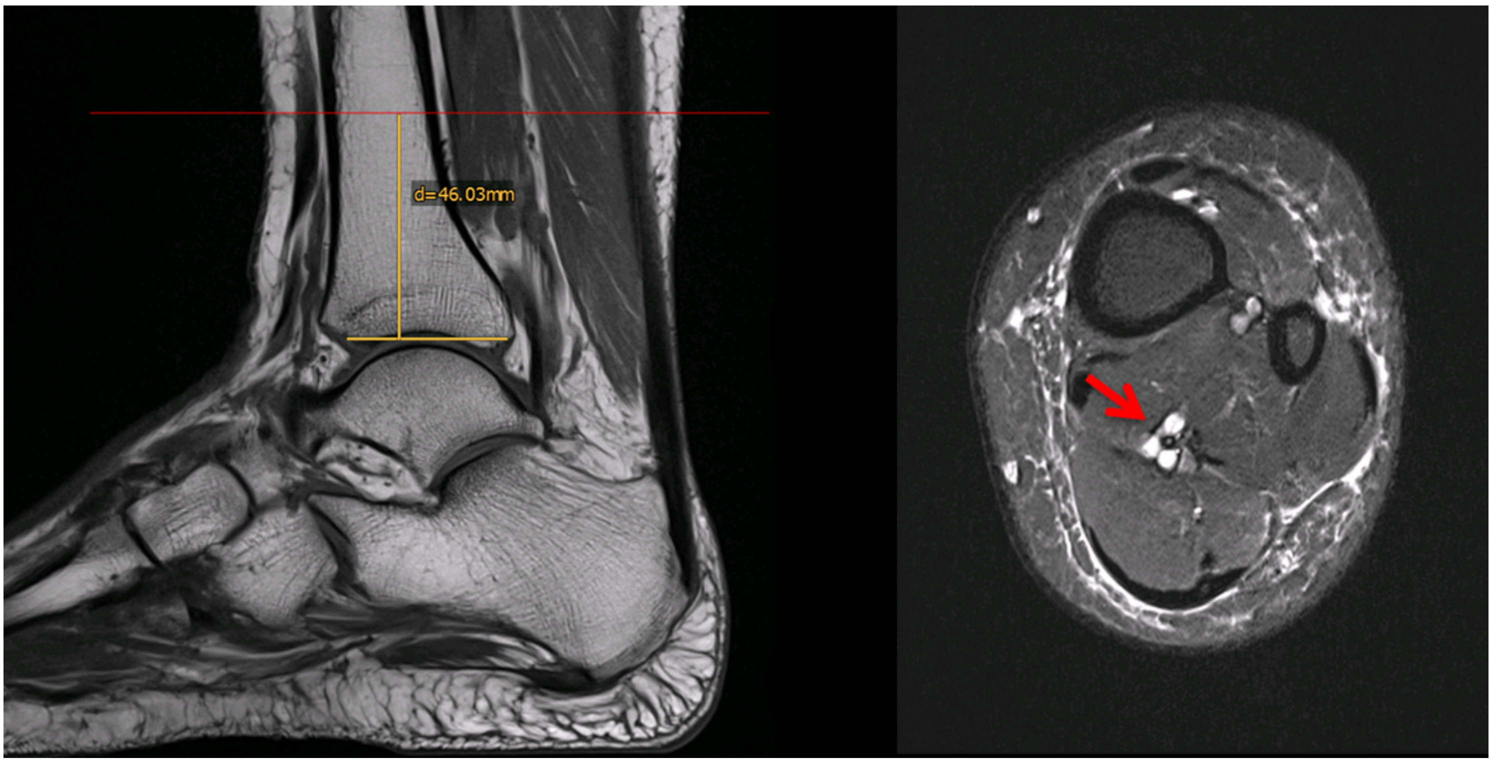

Figure 1

The height was determined on the sagittal plane by calculating the distance from the upper ankle joint line. The red arrow marks the neurovascular bundle.

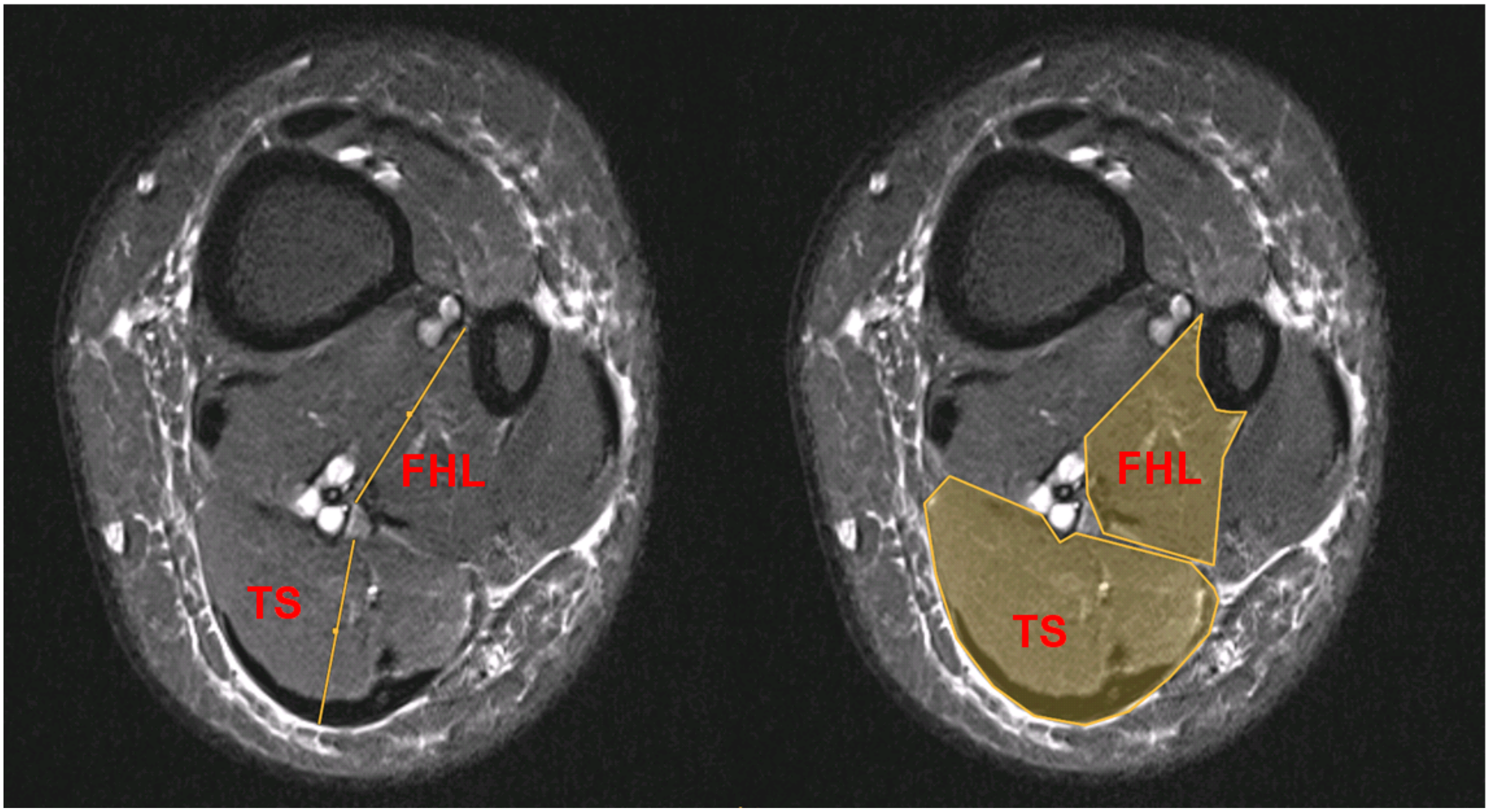

Figure 2

Measurement of diameter and area of FHL and TS muscle bellies.

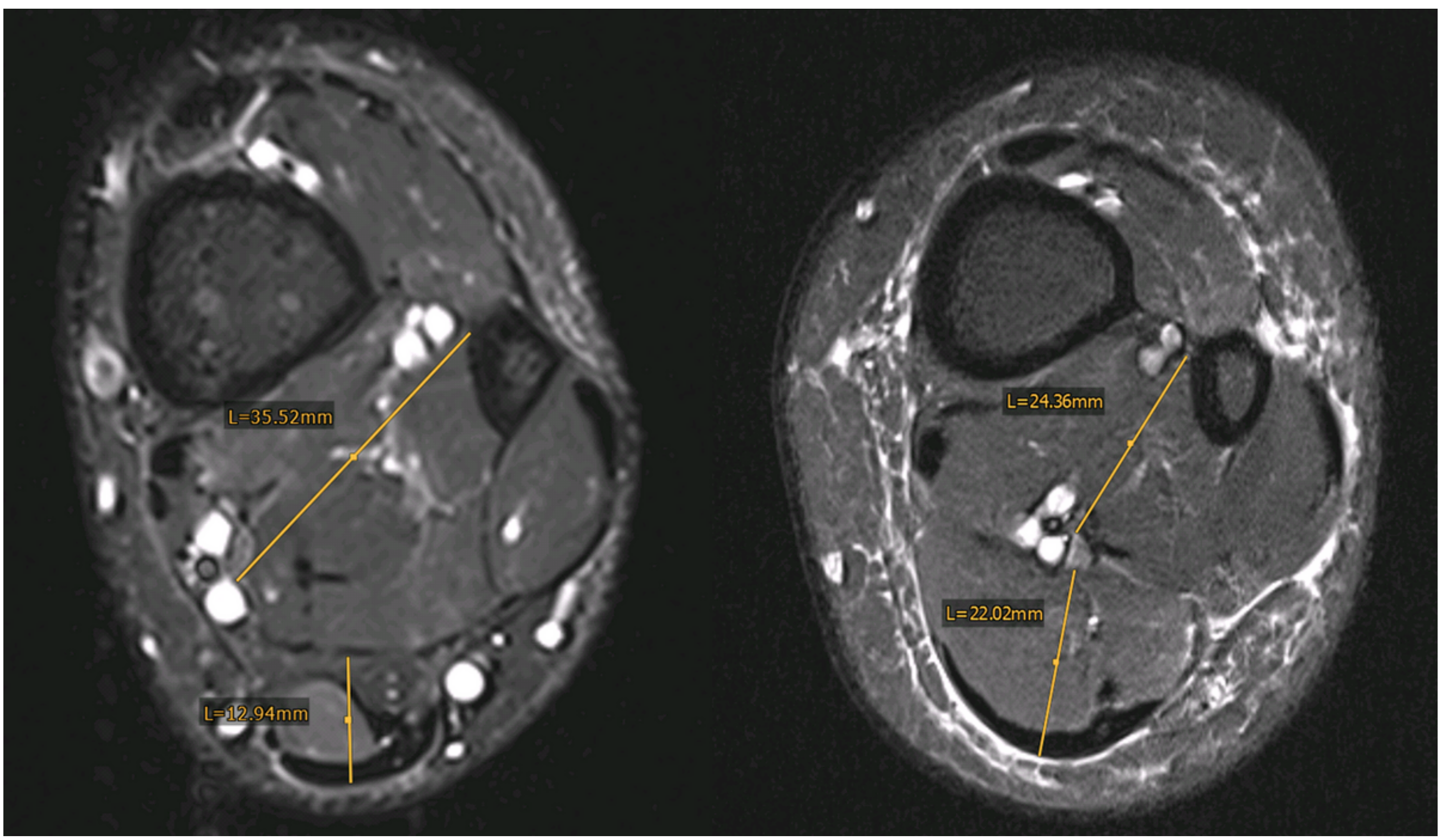

Figure 3

An example of two participants (left from Achilles tendinopathy group and on the right-side control group). Obvious quantitative differences can be observed.

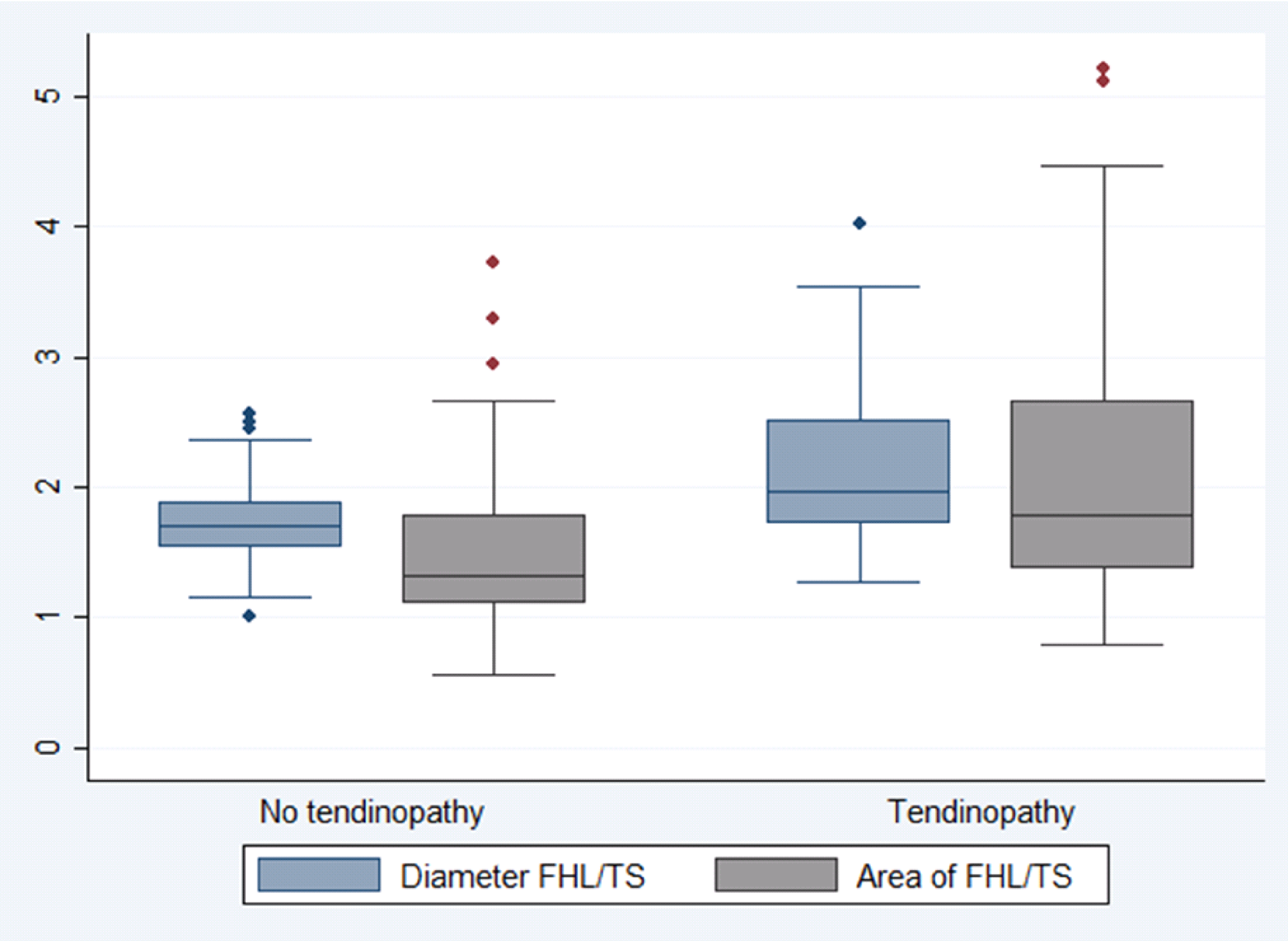

Figure 4

Ratios of diameter and area compared between study groups. The boxplots represent medians of the ratios of FHL/TS (blue for diameter and gray for area).

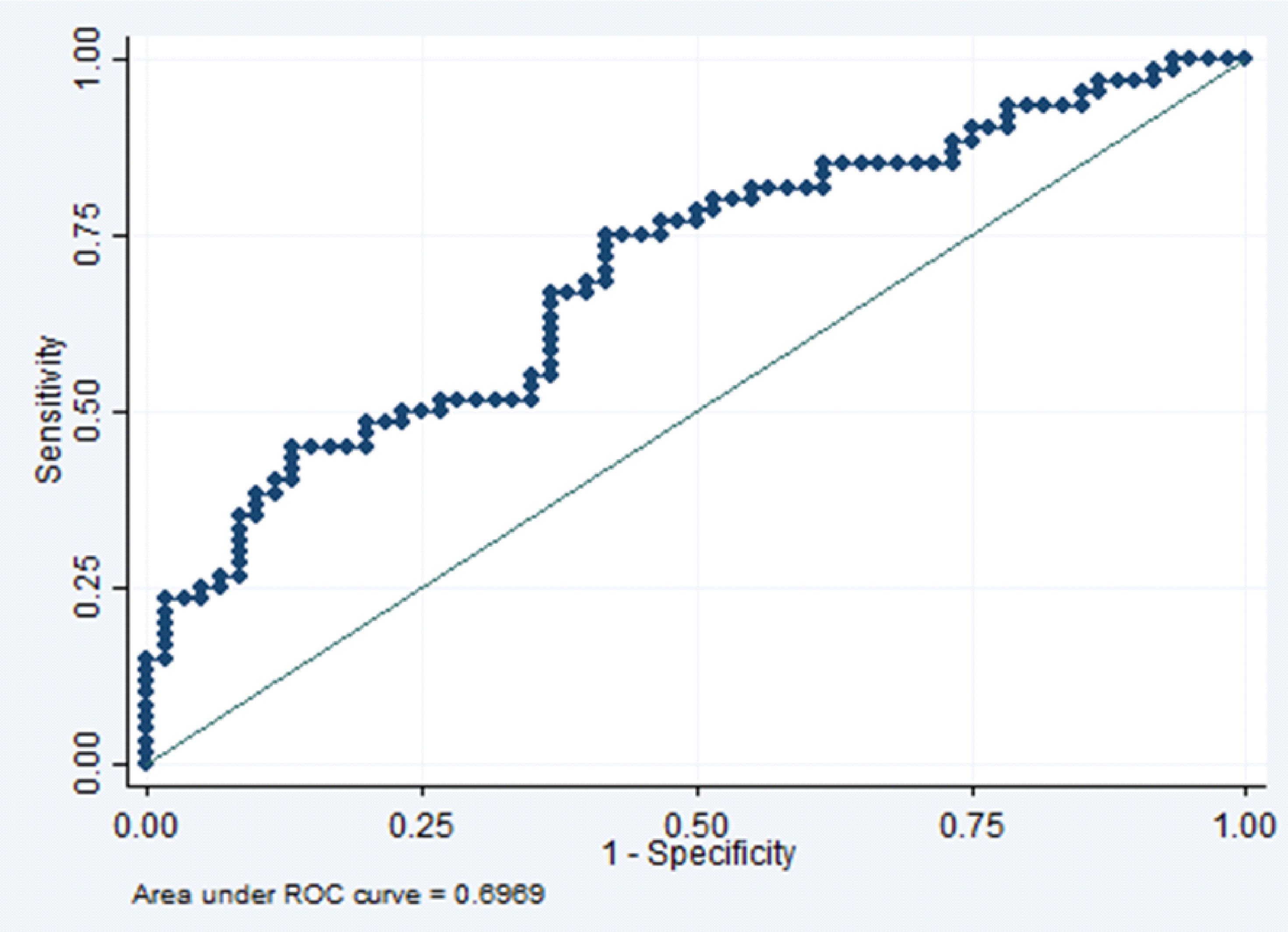

Figure 5

Receiver operating characteristic (ROC) curve assessing diameter ratio FHL/TS. AUC=0.6969 (95 percent [%] confidence interval [CI] 0.645-0.810). At a chosen cut-off point of a ratio of 2.0 and above, there was a sensitivity of 47% and specificity of 90% for concomitant signs of Achilles tendon tendinopathy.