

Musculoskeletal Ultrasound for the Diagnosis of Plantar Fasciitis: An Accuracy and Diagnostic Yield Study

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Objective: To evaluate the accuracy of musculoskeletal ultrasound measurement of plantar fascia thickness and shear wave elastography (SWE) calculation of Young's modulus in the diagnosis of plantar fasciitis (PFis), and to explore whether it will have any impact on clinical decision-making, rather than just using established diagnostic methods of clinical symptoms and signs.

Methods: A diagnostic single-center study was conducted in 60 patients with PFis and 64 patients with other types of heel pain. The sensitivity and specificity of musculoskeletal ultrasound in the diagnosis of PFis were calculated according to the diagnostic criteria for PFis recommended by the Clinical Practice Guide for PFis of the American Physical Therapy Association (APTA) Orthopaedic Branch. The analysis of the receiver operating characteristic curve of the subjects was used to study the accuracy of the diagnosis of PFis by two indicators alone and two indicators jointly.

Results: The thickness of plantar fascia measured by musculoskeletal ultrasound and the area under the curve (AUCs) calculated by shear wave elastography for diagnosing PFis were 0.925 and 0.917, respectively, and the optimal cutoff values were 3.15 mm (sensitivity: 100.0%, specificity: 81.3%) and 63.24 kPa (sensitivity: 78.3%, specificity: 92.2%), respectively. The area under the curve (AUCs) for the combined diagnosis of the two is 0.973 (sensitivity: 93.3%, specificity: 93.8%).

Conclusion: The thickness of plantar fascia measured by musculoskeletal ultrasound and Young's modulus calculated by SWE have high accuracy in diagnosing PFis, and the combined diagnosis of the two can improve the diagnostic accuracy of patients with PFis.

Keywords: plantar fasciitis, shear wave elastography, musculoskeletal ultrasound, diagnosis, accuracy

Introduction

PFis is a kind of disease that causes repeated micro trauma due to biomechanical overuse of the plantar fascia, which leads to degeneration of the plantar fascia and pain in the patient's foot.¹ At present, the diagnostic method of PFis is mainly clinical diagnosis. Imaging examination can confirm or exclude other causes of heel pain,^{2,3} but imaging, especially ultrasonic diagnosis, lacks evidence. Therefore, there is an urgent need for effective imaging indicators to diagnose PFis.

Musculoskeletal ultrasound examination, as a safe, efficient, and low-cost examination method, is increasingly being applied to the diagnosis of orthopedic diseases.⁴ The current understanding of PFis by ultrasound includes hypoechoic areas within the fascia, fluid accumulation around the fascia, and plantar fascia thickening.¹ Previous studies by some scholars have suggested that plantar fascia thickness >4mm is considered abnormal.⁵ However, in PFis patients, ultrasound may not always observe this phenomenon.^{6,7} SWE can provide changes in tissue elasticity indicators, and this technology has developed rapidly and is increasingly being used for evaluating the elasticity of musculoskeletal tissue.⁸ SWE can calculate the Young's modulus of tissues, which can provide information on elasticity and stiffness. Its clinical application has been widely recognized.^{9,10}

The purpose of this study was to evaluate the accuracy of musculoskeletal ultrasound measurement of plantar fascia thickness and SWE calculation of Young's modulus in the diagnosis of Plantar fasciitis in an extensive prospective study.

Materials and Methods

This study was a single center prospective study. This study was conducted according to the ethical principles of the Declaration of Helsinki and approved by the Medical Research Ethics Committee of First Clinical Medical College, Shaanxi University of Chinese Medicine (NO: XAZYYS2019-26), and all enrolled members had informed consent.

Study Design and Objects

We included heel pain patients aged ≥ 18 y who visited our outpatient clinic from January 2023 to May 2023. We excluded patients with foot injuries, previous foot surgeries, and treatment within 3 months (such as local injection, shock wave therapy, stretching, local drug therapy, etc.).

Two experienced clinicians divided the patients into PFis patients group and non-PFis patients group according to the following diagnostic criteria for Plantar fasciitis of the American Physical Therapy Association (APTA) Orthopaedic Branch.¹¹ Diagnostic criteria: (1) Pain in the medial sole and heel of the foot: most pronounced in the initial steps after a period of inactivity, but also worsens after prolonged weight bearing; (2) Heel pain caused by recent increase in weight-bearing activities; (3) Pain during palpation and compression of the proximal plantar fascia; (4) Limited range of motion in active and passive ankle dorsiflexion; (5) Windlass test positive; (6) Tarsal tunnel test negative, patients were divided into PFis patients group and non-PFis patients group. Subsequently, ultrasound physicians performed musculoskeletal ultrasound examinations on both groups of patients.

Measurement of Plantar Fascia Thickness and Young's Modulus

Using an ultrasound diagnostic instrument (GE LOGIQ E9) with a probe frequency range of 7–15 MHz for examination. Two professional technicians with over 5 years of ultrasound work experience will conduct the examination separately, and the two inspectors are unaware of each other's examination results. Measurement position: at the insertion point of the plantar fascia and calcaneus. During the examination, instruct the subject to lie prone, expose the soles of the feet, keep the ankle joint in a neutral position, and ensure that the tested area is exposed under the probe. Perform a two-dimensional ultrasound examination first and measure the thickness of the plantar fascia. Enable SWE mode, adjust the size and depth of the measured target area appropriately, freeze the image after it stabilizes, activate the elastic function provided by the instrument, measure the Young's modulus value of the plantar fascia, and repeat the measurement three times to calculate the average value.

Accuracy of Musculoskeletal Ultrasound in the Diagnosis of Plantar Fasciitis

We evaluated the accuracy of detecting PFis using the receiver operating characteristic curves (ROCs). In addition, we calculated the area under the curves (AUCs) to compare the accuracy of plantar fascia thickness and Young's modulus in diagnosing PFis.

Relationships Between the Visual Analog Scale for Pain and Plantar Fascia Thickness or Young's Modulus

Pain assessment was assessed using the visual analog scale (VAS) for pain (with 0 indicating no pain and 10, the worst pain that the patient can imagine). And we evaluated the relationship between VAS for pain and plantar fascia thickness or Young's modulus.

Statistical Analysis

Using SPSS 22.0 software, a homogeneity of variance test was conducted on the continuous variables of two groups of patients. Chi-squared test was used to compare the statistical differences between the two groups. The age, height, weight, plantar fascia thickness, and Young's modulus of the two groups of patients were compared using independent

sample T-tests. The working characteristic curve of the subject is used to determine the rationality of the diagnosis. Youden's index is used to determine the critical value of plantar fascia thickness and Young's modulus that may have diagnostic value. To investigate the relationship between VAS for pain and plantar fascia thickness or Young's modulus, we used Pearson correlation analysis. The difference of $P < 0.05$ is considered statistically significant.

Power Analysis

The effect size for the difference in the plantar fascia thickness between the PFis and non-PFis groups was 2.069, which is calculated using the means and standard deviations of plantar fascia thickness in both groups (4.05 ± 0.74 degrees and 2.61 ± 0.64 degrees in both groups, respectively). The effect size of 2.069 indicated that a minimum sample size of 5 in each group would be required to detect the difference with 80% power at a 5% significance level. Similarly, the effect size for the difference in the plantar fascia thickness between the PFis and non-PFis groups was 1.055, which is calculated using the means and standard deviations of Young's modulus in both groups (55.92 ± 11.13 degrees and 100.29 ± 58.44 degrees in both groups, respectively). The effect size of 1.055 indicated that a minimum sample size of 17 in each group would be required to detect the difference with 80% power at a 5% significance level. Therefore, the sample size in our study is sufficient to demonstrate the existence of such differences.

Results

The Number of Patients and Patients' Characteristics

We screened 167 patients with heel pain, of which 43 were excluded because they met the exclusion criteria, and ultimately included 124 patients with heel pain. According to the clinical diagnostic criteria, 60 patients were diagnosed as PFis, 64 patients were diagnosed as non PFis, and all patients had unilateral heel pain (Figure 1). And the diagnostic

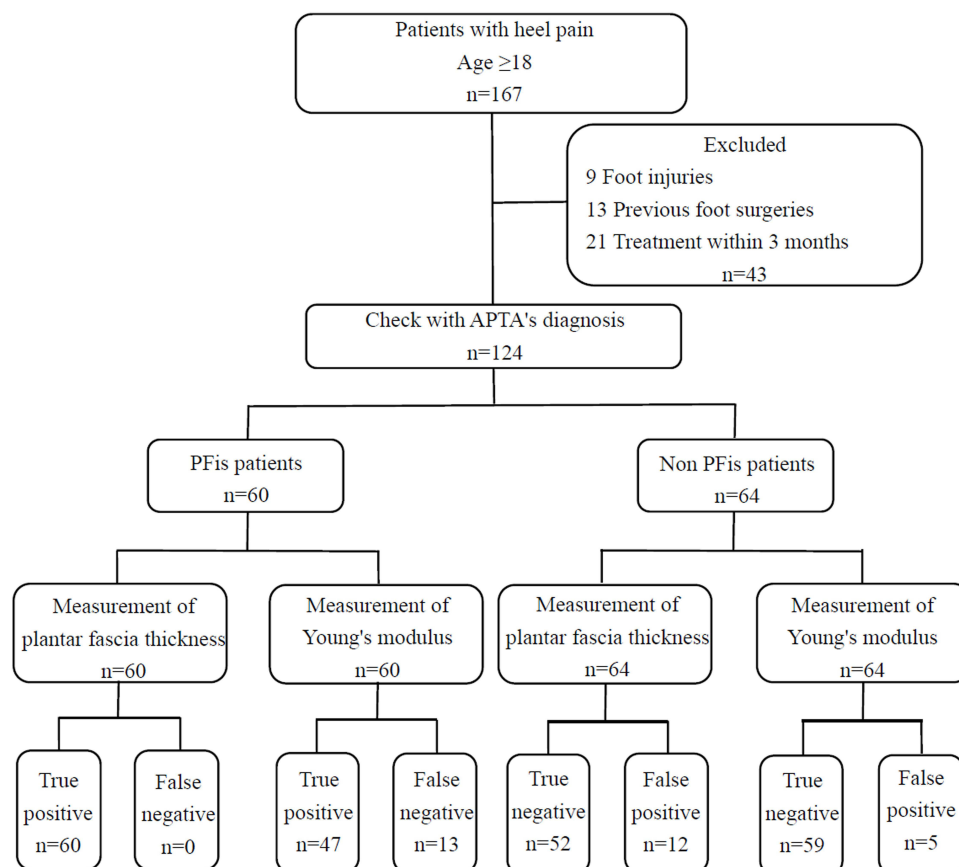


Figure 1 Patient flow.

Abbreviations: APTA, American Physical Therapy Association; PFis, plantar fasciitis.

grouping results of the two physicians are consistent. There was no statistically significant difference in gender, age, weight, and height between the two groups ($P>0.05$), indicating comparability (Table 1).

Comparison of Plantar Fascia Thickness and Young's Modulus Between the PFis and Non PFis Patient Groups

Compared with the non-PFis group, the PFis group has a significantly larger plantar fascia thickness and a significantly smaller Young's modulus, with statistically significant differences (Table 2). The consistency between the plantar fascia thickness and Young's modulus measured by two ultrasound physicians is high, as shown in Table 3.

Accuracy of Diagnosis of Plantar Fasciitis

In the diagnosis of various indicators, the optimal cutoff value, area under the curve, sensitivity, and specificity of the plantar fascia thickness measurement method are 3.15, 0.925, 100% and 81.3% (95% CI: 0.877–0.973), respectively. The optimal cutoff value, area under curve, sensitivity, and specificity of the plantar fascia Young's modulus method are 63.24, 0.917, 78.3% and 92.2% (95% CI: 0.871–0.963), respectively. The area under the curve, sensitivity, and specificity for the combined diagnosis of the two were 0.973, 93.3%, and 93.8% (95% CI: 0.947–1.000), respectively (Table 4). The receiver operating characteristic curves are shown in Figure 2.

Relationships Between Visual Analog Scale for Pain and Plantar Fascia Thickness or Young's Modulus

The results of the Pearson correlation analysis are shown in Table 5. VAS for pain is significantly correlated with plantar fascia thickness and Young's modulus. And VAS for pain increases with the increase of plantar fascia thickness. On the contrary, VAS decreases with the increase of Young's modulus.

Table 1 Characteristics of Patients with Heel Pain

	Gender (Male/Female, n)	Age (Years)	Weight (kg)	Height (m)
Non PFis patients	36/28	41.5 ± 15.1	67.7 ± 12.7	1.70 ± 0.07
PFis patients	36/24	43.6 ± 10.1	71.6 ± 11.4	1.70 ± 0.08
P-value	0.672	0.793	0.212	0.921

Abbreviation: PFis, plantar fasciitis.

Table 2 Comparison of Plantar Fascia Thickness and Young's Modulus Between Two Groups of Patients

	Plantar Fascia Thickness (mm)	Young's Modulus (kPa)
Non PFis patients	2.61 ± 0.64	100.29 ± 58.44
PFis patients	4.05 ± 0.74	55.92 ± 11.13
P-value	<0.001	<0.001

Abbreviation: PFis, plantar fasciitis.

Table 3 Intraobserver Reliability of Ultrasound Examination. CI, Confidence Interval

	Intraobserver Reliability (95% CI)
Plantar fascia thickness	0.98 (0.98–0.99)
Young's modulus	0.99 (0.98–0.99)

Table 4 The Accuracy of Diagnosing Plantar Fasciitis Based on Musculoskeletal Ultrasound

	Optimal Cutoff Value	95% CI	AUC	Se(%)	Sp(%)	Youden Index
Thickness method	3.15 mm	0.877–0.973	0.925	100	81.3	0.813
Young's modulus method	63.24 kPa	0.871–0.963	0.917	78.3	92.2	0.705
Combined diagnosis	/	0.947–1.000	0.973	93.3	93.8	0.871

Abbreviations: CI, confidence interval; AUC, area under the curve; Se, sensitivity; Sp, specificity.

Discussion

PFis is a chronic disease characterized by pain in the anterior medial aspect of the calcaneus during morning or rest weight-bearing, exacerbated by palpation of the anterior medial aspect of the calcaneus and passive dorsiflexion of the first toe.¹¹ At present, the diagnosis of Plantar fasciitis is mainly based on clinical symptoms and physical examination. Imaging examination is usually introduced as a differential diagnosis, and quantitative indicators, especially diagnostic indicators, are relatively lacking. Ultrasound technology can provide tissue biological information and is increasingly being applied in the diagnosis of PF with advantages such as objectivity, economy, and real-time.

The normal plantar fascia is a dense and tough tissue that contains a large amount of collagen fibers.¹² Its function is to support the arch of the foot and is a fibrous aponeurosis. The ultrasound characteristics of PFis mainly include thickening of the fascia and decreased echo. However, there are many factors that affect the echo of the plantar fascia, including factors such as excessively keratinized skin that can easily cause ultrasound attenuation. Therefore, current research suggests that the thickening of the plantar fascia under ultrasound examination has important value in the diagnosis of PF.¹³ The thickness of the normal plantar fascia is approximately 2.20–2.50 mm, and previous studies have suggested that it is abnormal when it thickens to greater than 4.0 mm.¹⁴ However, in our previous clinical observations, the thickness of the plantar fascia in many patients with PFis did not reach 4.00mm. In this study, the plantar fascia

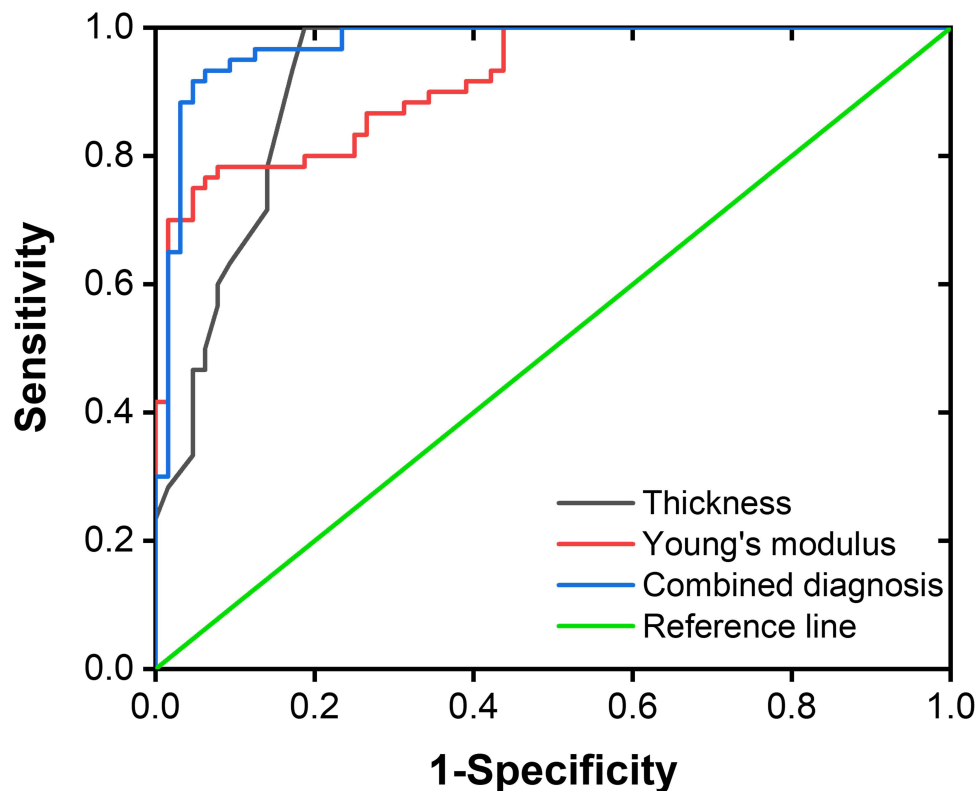
**Figure 2** Receiver-operating characteristic curves in the non plantar fasciitis and plantar fasciitis groups.

Table 5 Pearson Correlation Analysis Between Vas and Plantar Fascia Thickness or Young's Modulus

	Pearson Correlation Coefficient	P-value
Plantar fascia thickness	0.91	<0.001
Young's modulus	−0.55	<0.001

thickness of the PFis group was significantly greater than that of the normal, and significantly thicker than that of the non-PFis group ($p < 0.001$). The optimal cutoff value of the plantar fascia thickness calculated by the receiver operating characteristic was 3.15 mm (sensitivity: 100.0%, specificity: 81.3%), and the area under the curve was 0.925. There is a certain difference between the optimal cutoff value and previous studies, which may be due to differences in physical factors between the local population and the previous study population. However, this result shows that ultrasound measurement of plantar fascia thickness has good diagnostic accuracy and value, and we need to consider the lower plantar fascia thickness to diagnose Plantar fasciitis in this area.

The hardness of the plantar fascia can reflect its biomechanical characteristics, and to some extent, it can also further understand the functional characteristics of the ankle. The decrease in muscle strength in the ankle region leads to an increase in local mechanical stress, thickening and fibrosis of the plantar fascia. Under SWE, the manifestation is a decrease in elasticity, which may be due to a decrease in fibrin content in the plantar fascia and hypertrophy of fibroblasts. Many studies have confirmed the application value of SWE in soft tissues, ligaments, and tendons.^{15–20} Alviti et al²¹ found that the plantar fascia, which reflects pain, is less elastic and softer. Due to the difficulty in objectively quantifying the hardness of the plantar fascia in patients with PFis through methods such as palpation and physical examination, objective indicators are needed to provide a basis for evaluating the condition of the plantar fascia. In this study, the Young's modulus of the plantar fascia in the PFis group was significantly lower than that in the non-PFis group ($p < 0.001$), indicating that the plantar fascia in the diseased group was softer, which is consistent with previous studies. The optimal cutoff value of Young's modulus calculated by receiver operating characteristic is 63.24 kPa (sensitivity: 78.3%, specificity: 92.2%), and the area under the curve was 0.917. This result shows that the Young's modulus calculated by shear wave elastography has good diagnostic accuracy and value.

At the same time, when the plantar fascia thickness measurement method and the Young's modulus method are combined for diagnosis, the area under the curve is 0.973 (sensitivity: 93.3%, specificity: 93.8%), and the diagnostic accuracy is higher than when the two methods are diagnosed separately.

The Pearson correlation analysis of this study shows that there is a strong correlation between the patient's VAS for pain and plantar fascia thickness and Young's modulus, and there is a certain linear relationship. This result suggests that the plantar fascia thickness and Young's modulus of the patient may have a certain impact on the severity of the patient's symptoms. This suggests that in clinical work, we can quantify these indicators to choose whether to take active intervention measures for patients.

There are several limitations worth considering in the research. Firstly, this experiment used a small sample size, single-center study. Secondly, we could not examine the etiologies of PFis.

Conclusions

This study showed that the method of measuring the thickness of plantar fascia by ultrasound and the Young's modulus calculated by shear wave elastography has a high diagnostic value for PFis, and the combined diagnosis of the two is more accurate than the separate diagnosis of the two.

Disclosure

The authors report no conflicts of interest in this work.

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