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Original article

Added Value of Shear Wave Elastography (SWE) for Evaluation of Patients with Plantar Fasciitis

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ABSTRACT

Background*:* **Background:** Plantar fasciitis is caused by degenerative changes and repetitive stress, and it is a common cause of heel pain. Ultrasound is a reliable diagnostic tool for PF, but not all patients exhibit changes on ultrasound, making additional techniques necessary. the plantar fascia mechanical properties can be assessed by Elastography, such as Strain elastography and shear wave elastography. Strain elastography is subjective and operator-dependent, while shear wave elastography provides a quantitative measure of tissue stiffness.

Method: This study is a case control that has been conducted on 30 PFis patients (clinically diagnosed) and 30 matched control healthy individuals with no pain. It aimed to determine the added value of elastography to B-Mode ultrasound in the PFis diagnosis in comparison with healthy people. PF thickness and SWE stiffness elasticity (Young's modulus in kPa and shear wave velocity in m/s) were measured 1 cm distally from the calcaneal insertion. Correlations with VAS, AOFAS and the 17-Italian Foot Function Index (17-FFI) were determined.

Results: Plantar fasciitis can be significantly assessed by SWE velocity and elasticity. There is a negative correlation between plantar fascia thickness and both SWE velocity and elasticity. Mean SWV value in healthy subjects was 5.92 m/s and in patients 3.02 m/s with a mean stiffness value of 109.1 kPa and 49.35 kPa respectively ($p < 0.001$). For SWV a cut-off value of 4.1 m/s had a specificity of 100 % and sensitivity of 93.33%. For stiffness a cut-off value of 48.1 kPa had a specificity of 100% and sensitivity of 76.67%. The mean thickness of healthy fascias was 2.93 mm (range 1.8-3.7) compared to 5.25 mm (range 3.4-8.3) in plantar fasciitis ($p < 0.001$) with cut off value about 3.7 had a specificity of 100 % and sensitivity of 90%.

Conclusion: Our study has proven that the diagnostic accuracy is improved by SWE compared to B-US and that the combination of B-US and SWE is a strong diagnostic tool in detection of PFis and may be helpful in diagnosing early cases.

Keywords: FFI; AOFAS; plantar fasciitis; SWV; Shear wave elastography (SWE).

Abbreviations: ROI: region of interest, PFis: plantar fasciitis, PF: plantar fascia, SWE: shear wave elastography, B-US: B-mode ultrasound, VAS: visual analogue score , FFI: foot function index .

INTRODUCTION:

Plantar fasciopathy or Plantar fasciitis or PFis, is a common cause of heel pain that is not caused by injury. It affects approximately 10% of global population in their lifetime at some point [1] and can significantly impact their quality of life, even though it is a self-limiting condition. Repetitive stress on the fascia and degenerative changes is believed to be the cause of PF [2,3]. Ultrasound is a well-established and reliable imaging technique used to diagnose plantar fasciitis, and it can detect

associated changes such as thickening, perifascial edema, and altered echogencity [4].

However, not all PF patients exhibit changes on ultrasound, additional techniques are necessary to evaluate the plantar fascia mechanical properties. Elastography is the technique that can reveal underlying histological changes affecting fascial elasticity [5,6], and two commonly used methods are shear wave elastography (SWE) and Strain elastography (SE). SE is subjective and operator-dependent, requiring repeated manual compressions to elicit tissue strain [7], and the resulting strain distribution is displayed as a color-coded elastogram. In contrast, SWE measures shear wave velocity generated by a probe to provide a quantitative measure of tissue stiffness. [8,9]

This case-control study aims to compare B-mode ultrasound and SWE (velocity and stiffness) findings in asymptomatic and symptomatic individuals. By analyzing and comparing these findings, valuable insights and cut-off values can be obtained and used in the diagnosis of PFis.

METHODS

Ethical Statement: The Zagazig University Institutional Review Board approved this case-control study (Approval No.9584-8-6-2022) that was conducted from June 2022 to December 2022 at the Radiology department of Zagazig University Hospital. The study included 60 participants (30 cases and 30 controls) referred from the Rheumatology, Rehabilitation, and Orthopedic Surgery departments and outpatient clinics, who provided written consents after being informed of the study's purpose and nature and the study has been carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans. To recruit participants for the research, specific criteria were employed to determine who was eligible for inclusion and who was not. Patients in the first group, referred to as the plantar fasciitis group, were identified through clinical diagnosis of plantar fasciitis based on their presentation of inferior heel pain that worsened after periods of inactivity and was most tender over the anteromedial aspect of heel. Patients with VAS pain score greater than 4 out of 10 and aged 18 years or older, regardless of gender, were included. In second group (the control group), asymptomatic individuals were chosen to match the ages, physical activity levels, and BMI of the plantar fasciitis group. These individuals had no history of pain or discomfort in either foot. Patients who met any of the following criteria were excluded from the study: unwillingness to participate, previous local injection, surgery or trauma, calcaneal or stress fractures, the presence of plantar fascia masses or tumors, or uncorrected congenital foot malformations.The imaging study for the research consisted of Ultrasonography and Shear Wave Elastography (SWE), which were performed in a standardized environment with a temperature of 20°C. A Toshiba Aplio 500 US scanner with multifrequency 5-18 MHz linear probe was used for sonographic examinations. The patients were lying in the prone position with the foot hanging relaxed over the examination table, and the measured foot was kept in a neutral position without any active or passive dorsiflexion of the big toe. The examination started with B-mode US before SWE, using a standardized examination protocol. Copious amounts of coupling gel were applied to the probe, and the operator used a superficial musculoskeletal examination protocol, freely adjusting the focus, gain, and contrast.B-Mode examination was performed in longitudinal and short-axis planes to evaluate echogenicity and thickness of plantar fascia. The maximum thickness of PF was measured towards calcaneal insertion, reduced echogenicity, along with other findings such as perifascial edema ware recorded. In Shear wave elastography, the transducer was kept stationary with light pressure and a generous amount of coupling gel during acquisition of each SWE sonogram, using B-mode to ensure longitudinal transducer alignment with the plantar fascia. A 2 cm^2 SWE measurement window was applied, and 2-mm-diameter ROI was manually tracked and centered to the thickest part of fascia within 1 cm from calcaneal insertion. Three quantitative measurements of shear wave stiffness (kPa) and velocity (m/s) were obtained after unfreezing and freezing, and the mean of the three measurements was obtained. Overall, the imaging study was conducted with meticulous attention to detail to ensure results obtained accuracy.

Statistical analysis : The program used for statistical analysis was SPSS version 20. Quantitative data were analyzed using mean, standard deviation (SD), median, and inter-quartile range (IQR), while frequency and percentage were used with qualitative data. Student t-test was used to compare means of different groups, while Fischer exact test to compare frequencies. Box plot was performed. The corresponding distribution tables were consulted to get the “P” (probability value). Statistical significance was accepted at a P-value $\leq$0.05while a P-value > 0.05 was considered insignificant

RESULTS

Evaluating the diagnostic accuracy of SWE in PFis diagnosis is the aim of the present study. The study enrolled 60 participants aged between 28-55

years, including 30 patients diagnosed with PFis and 30 age, sex, BMI, and occupation-matched healthy controls. As shown in Table 1, no significant differences were observed in the demographic characteristics of the two groups. Group 1 (Plantar fasciitis group) consisted of 30 patients with clinically indicative plantar fasciitis ,of these patients, 80% (24) were female and 20% (6) were male, with a mean age of 42.1 +/- 6.88 years. Group 2, the control group, included 30 matched healthy individuals without any complaints of heel pain, of which 40% (12) were male and 60% (18) were female, with a mean age of 39.27 +/- 5.57 years.In group 1 (Plantar fasciitis group), several symptoms were reported, including foot stiffness (26.67%), foot swelling (43.33%), morning pain (63.33%), pain while walking or standing (46.67%), and limping issues (16.67%). The VAS score ranged from 6 to 10 in the group, with a mean of 8.95 ± 1.8. The FFI score ranged from 38.6 to 91.3, with a mean of 57.1 ± 18.5, and the AOFAS score ranged from 25 to 75, with a mean of 50.7 ± 12.9. In contrast, group 2, the healthy control group, had no reported symptoms, with zero VAS and FFI scores and an AOFAS score of 100 (Table 1).B-mode evaluation revealed decreased plantar fascia echogenicity in 70% of the PF group, while all individuals in the control group had homogeneous plantar fascia echogenicity. Edema was detected in 56.67% of the case group compared to 0% of the control group. Moreover, the plantar fascia thickness in patients with PF was significantly increased compared to that of the control group, with a mean of 5.25 mm (SD 1.32, range 3.4-8.3 mm) versus a mean of 2.93 mm (SD 0.49, range 1.8-3.7 mm) in controls (p <0.001*) (Table 2). The obtained cut-off upper normal limit for thickness was 3.7 mm (AUC: 0.955) with a specificity of 100% and a sensitivity of 90% (Fig. 1).Furthermore, the study found a significant negative correlation between the thickness of the plantar fascia and shear wave velocity (SWV) (r= -0.534, P= 0.002) and shear wave elasticity (SWE) (r= -0.537, P= 0.002) (Table 3). The m/s and kPa levels of the feet with PF were lower than those of the control group (P < 0.001) (Table 2). The ROC analysis for SWV resulted in a cut-off value of 4.1 m/s (AUC: 0.99), with a specificity of 100% and a sensitivity of 93.33%. For stiffness, a cut-off value of 48.1 kPa (AUC: 0.903) was found with a specificity of 100% (95% CI: 61.9-95.24%) and a sensitivity of 76.67% (Table 4) and (Fig.1).

Table 1: Demographic and clinical Data of the studied patients:

		Group 1 (n=30)	Group 2 (n=30)	P value
Age (years)	**Mean ± SD**	42.1 ± 6.88	39.27 ± 5.57	0.085
	Range	29 – 55	28 – 55	
Sex	**Male**	6 (20%)	12 (40%)	0.091
	Female	24 (80%)	18 (60%)	
BMI (kg/m^2)	**Mean ± SD**	31.63 ± 2.59	30.23 ± 3.88	0.105
	Range	26.95 – 36.11	19.84 – 34.55	
Occupation	**Builder**	1 (3.33%)	0 (0%)	0.119
	Worker	2 (6.67%)	6 (20%)	
	Co-worker	1 (3.33%)	0 (0%)	
	Office worker	1 (3.33%)	0 (0%)	
	Electric worker	2 (6.67%)	0 (0%)	
	Technician	0 (0%)	4 (13.33%)	
	Teacher	2 (6.67%)	3 (10%)	
	Doctor	5 (16.67%)	8 (26.67%)	
	Nurse	9 (30%)	6 (20%)	

	Housewife	7 (23.33%)	3 (10%)	
Clinical presentation				
	Foot stiffness	**8 (26.67%)**	-	
	Foot swelling	**13 (43.33%)**	-	
	Pain at early morning	**19 (63.33%)**	-	
	Pain at walking or longstanding	**14 (46.67%)**	-	
	Limping	**5 (16.67%)**	-	
VAS	**Mean ± SD** **Range**	**8.95 ± 1.8** 6-10	0	
FFI	**Mean ± SD** **Range**	**57.1 ± 18.5** 38.6 % -91.3%	0	
AOFAS	**Mean ± SD** **Range**	**50.7 ± 12.9** 25-75	100	

BMI: body mass index VAS :visual analogue scale FFI : foot function index AOFAS :American orthopedic foot & ankle society

Table2: Planter fascia B-mode and SWE for the studied groups .

		Group 1 (n=30)	Group 2 (n=30)	P value
B-Mode				
Echo-pattern	**Isoechoic**	9 (30%)	30 (100%)	**<0.001***
	Hypoechoic	21 (70%)	0 (0%)	
Edema	**Yes**	17 (56.67%)	0 (0%)	**<0.001***
	No	13 (43.33%)	30 (100%)	
Thickness (mm)	**Mean ± SD**	5.25 ± 1.32	2.93 ± 0.49	**<0.001***
	Range	3.4 - 8.3	1.8 - 3.7	
SWE				
Shear wave velocity (m/s)	**Mean ± SD**	3.01 ± 0.74	5.92 ± 1.21	<0.001*
	Range	1.9 - 4.8	4.4 - 9.1	
Shear wave elasticity (Kpa)	**Mean ± SD**	49.35 ± 18.3	109.1 ± 26.66	<0.001*
	Range	18 – 82	65.4 - 164.2	<0.001*

Table3: Correlation between shear wave elastography and thickness (mm) by B-mode ultrasonography of group 1 (n=30)

	Plantar fascia thickness (mm)	
	R	**P**
Shear wave velocity (m/s)	-0.534	**0.002***
Shear wave elasticity (Kpa)	-0.537	**0.002***

*: significant as P value ≤0.05 ,.

Table4: Diagnostic accuracy of plantar fascia shear wave elastography and thickness (mm) by B-mode ultrasonography in assessing plantar fasciitis:

	Cut-off	AUC	Sensitivity	Specificity	PPV	NPV	P value
Shear wave velocity (m/s)	≤4.1	0.990	93.33	100	100	93.7	**<0.001***
Shear wave elasticity (Kpa)	≤48.1	0.903	76.67	100	100	81.1	**<0.001***
Thickness (mm)	>3.7	0.955	90	100	100	90.9	**<0.001***

AUC: area under the curve, PPV: positive predictive value, NPV: negative predictive value, *: significant as P value ≤ 0.05

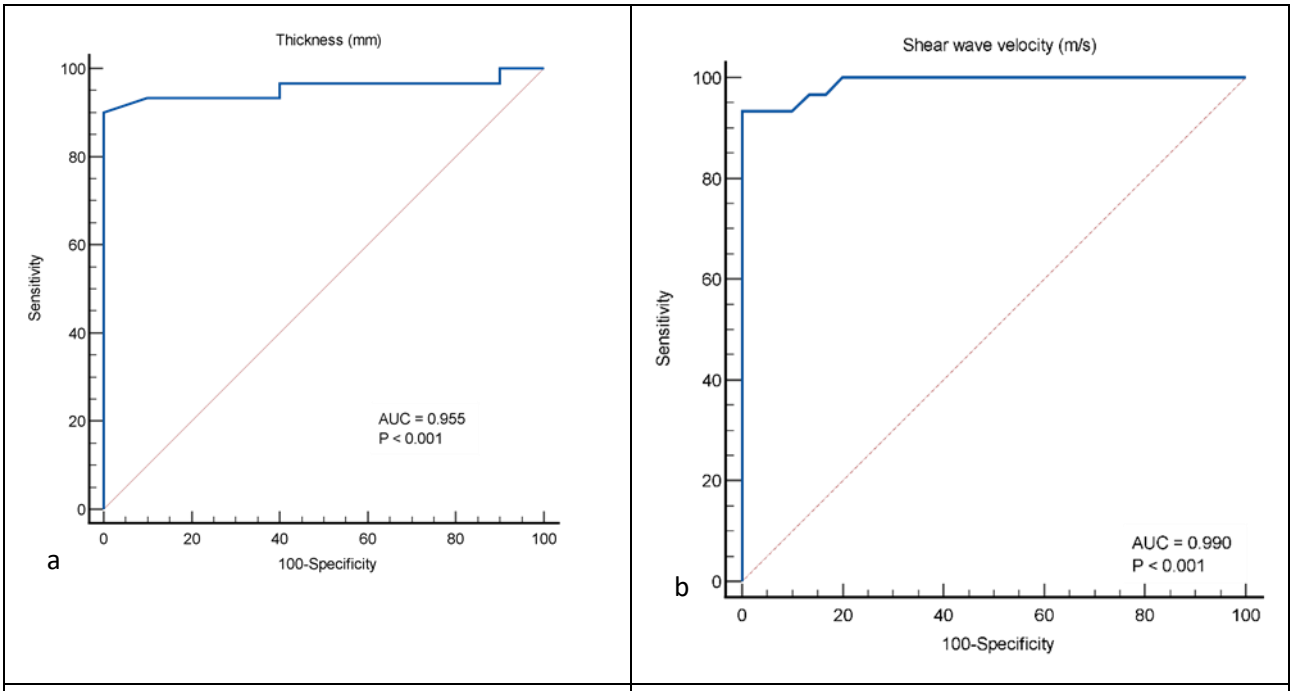

Figure 1

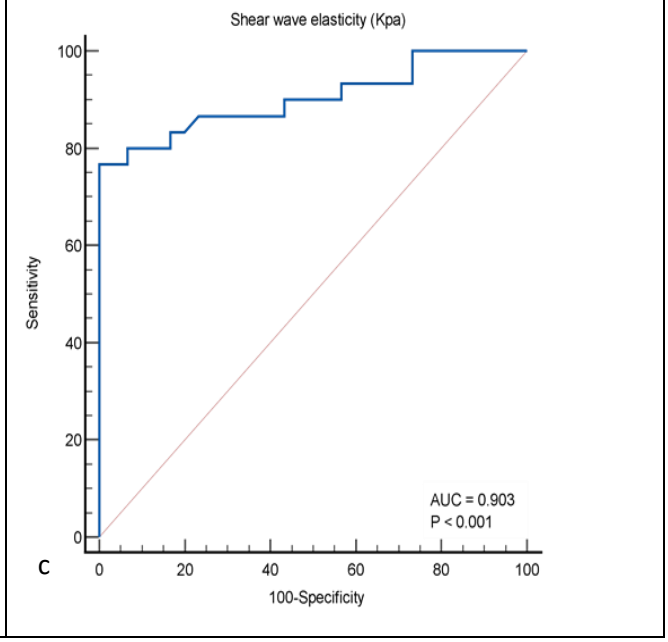

Figure (1)

a) ROC curve of plantar fascia thickness in assessing plantar fasciitis.
b) ROC curve of plantar fascia shear wave velocity in assessing plantar fasciitis

c) ROC curve plantar fascia shear wave elasticity in assessing plantar fasciitis

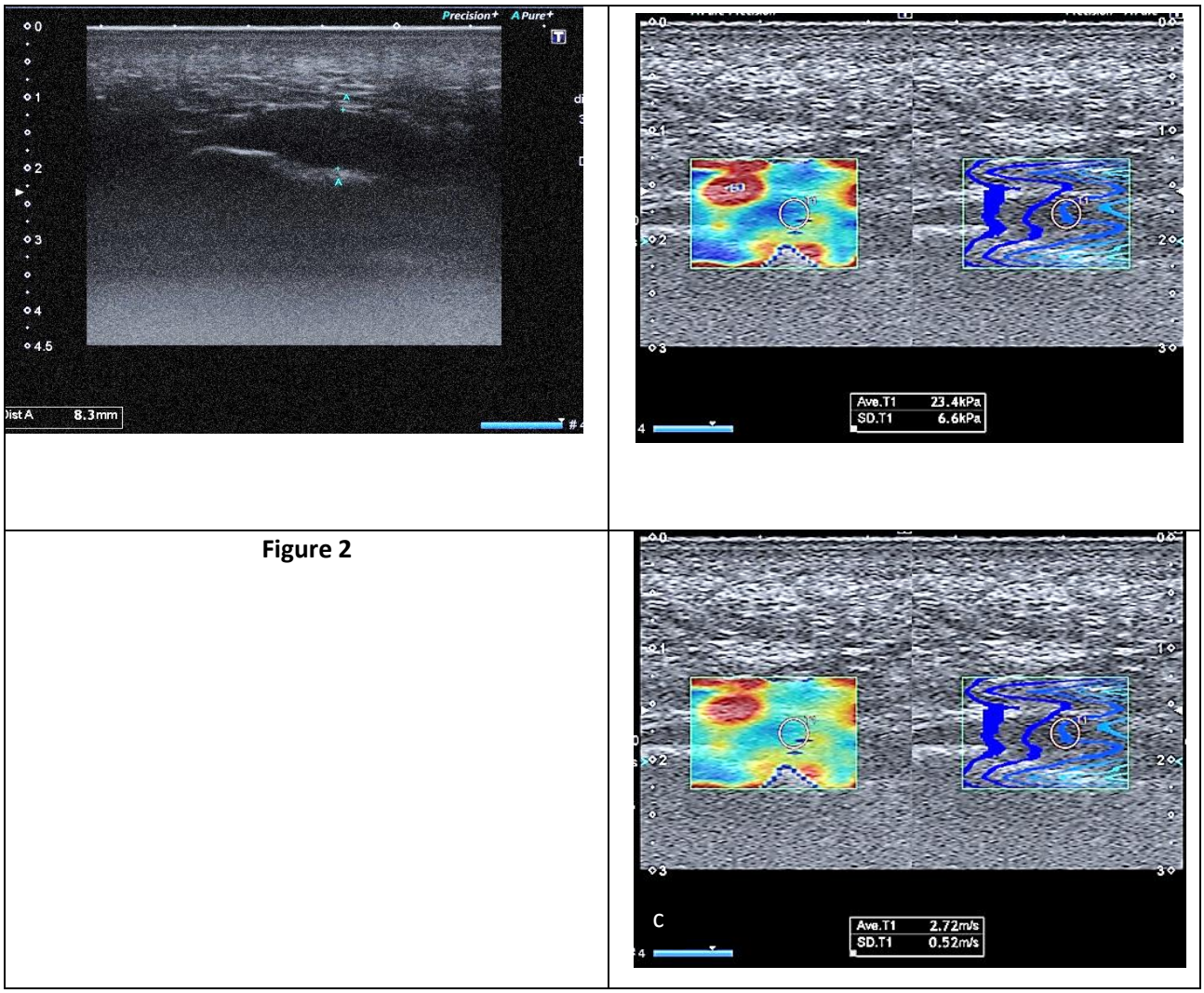

Figure 2

Figure (2) presents imaging findings of a 55-year-old female patient who weighs 111kg and complains of pain at early morning and walking, with tenderness over the lateral aspect of the heel. The patient's VAS score is about 9/10, and FFI is about 58.6%, while AOFAS is 54/100.

A) The longitudinal B-mode ultrasound image at the level of the plantar fascia insertion, 1 cm distal to the calcaneus, revealed an average thickness of 8.3 mm with a hypoechoic pattern and perifascial edema.
B) Shear wave elastography with ROIs (Regions of Interest) 1 cm from the calcaneal insertion revealed an average elasticity of 23.4 kPa.
C) Shear wave elastography with ROIs 1 cm from the calcaneal insertion revealed an average velocity of 2.73 m/sec.

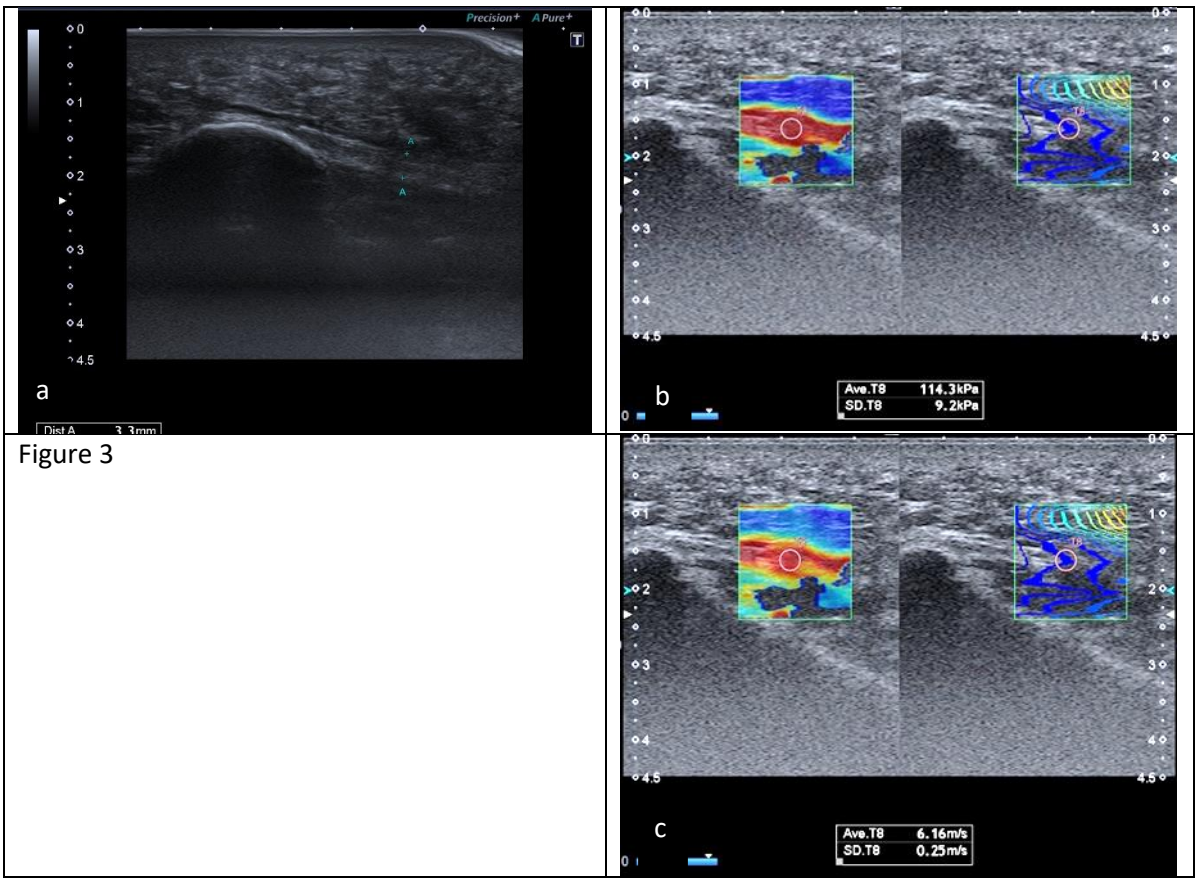

Figure 3

Figure (3): depicts a 30-year-old female patient who weighs 79 kg and reports no pain in either heel, with a Vas score of 0 and an FFI score of 0, while her AOFAS score is 100.

A) The longitudinal B-mode ultrasound image at the level of the plantar fascia insertion reveals an average thickness of 3.3 mm with an isoechoic pattern and no perifascial edema.
B) The shear wave elastography with ROIs at 1 cm from the calcaneal insertion shows an average elasticity of 114.3 kPa
C) An average velocity of 6.16 m/sec.

DISCUSSION

PF is is a common condition which affects all ages and genders individuals, It is a low grade inflammatory process where repetitive microtrauma induces microtears which elicit an inflammatory reaction.Diagnosis is based on history of patients, physical examination, and morning pain presentation on the undersurface of the heel that improves with walking and worsens with prolonged activity. However, the symptoms of PF can be mimicked by other disorders, leading to the use of different imaging modalities like radiography, ultrasound, MRI, and SWE for confirmation [10-12].Our research supports using B-mode ultrasound (US) as a dependable diagnostic tool for detecting plantar fasciitis. We suggest that loss of PF elasticity can be an additional diagnostic criterion for PFis on B-mode sonography.

Regarding B-mode plantar fascia features, PF thickness in the group with PFis was found to be significantly higher compared to the healthy group (5.25 mm ± 1.32 VS 2.93 ± 0.49 mm), in accordance with previous studies by Jiang et al [13] and Baur et al [14]. Other B-mode features such as reduced echopattern and associated edema were detected in the plantar fasciitis group than control group, that agree with other studies [15,16,17].However, there is currently no widely accepted guidance on how to position the metatarsophalangeal (MTP) joints during plantar fascia thickness measurement, and literature varies in its protocols as reported by Wu et al [18]. To minimize errors caused by muscle tension, we employed a relaxed feet positioning approach that is both comfortable for the patient and examiner.Regarding plantar fascia thickness, our results were contradictory to those of a systematic review by McMillan et al [19], who provided support for the known reference value of the 4.0 mm threshold value. Although we found a statistically significant difference in plantar fascia

thickness between our groups, our analysis revealed a cut-off value (>3.7) for plantar fascia thickness in clinically diagnosed patients that was meaningful (AUC= 0.955, 90% sensitivity, 100% specificity). These results were consistent with Groshar et al and Kim et al [20,21], who reported cut-off values of >3.9 (sensitivity of 74.1% and a specificity of 71.4%) and >3.8 mm (AUC: 0.63, sensitivity of 48.6% and a specificity of 90.6%), respectively. Wu and his colleagues [22] also reported no statistically significant differences between normal plantar fascia thickness and plantar fasciitis regarding thickness (p = 0.11). Based on these results, we hypothesize that loss of plantar fascia elasticity can be an additional diagnostic criterion for plantar fasciitis on B-mode sonography, especially in patients with plantar fascial thickness less than 4 mm.

It is commonly agreed that excessive mechanical stress and strain on plantar fascia cause microscopic tears, followed by an inflammatory response for healing. in plantar fasciitis patients, several histological findings include angiofibroblastic hyperplasia, mucoid ground substance increase, fiber disorientation and collagen degeneration. These changes in the plantar fascia at the microscopic level may result in alterations in elasticity [4,23]. Regarding range of plantar fascia thickness in PFis group and the following sonoelastographic results we support Wu et al who indicated that patients may have normal plantar fascia thickness with clinical symptoms of plantar fasciitis and exhibit less elastic plantar fascia. In these patients, the symptoms may be related to alterations in plantar fascial elasticity rather than changes in morphology. Our sonoelastography results showed that plantar fasciitis patients had significantly lower average SWV values of 3.01 m/s and stiffness values of 49.35 kPa compared to healthy subjects with average SWV values of 5.92 m/s and stiffness values of 109.1 kPa (p value <0.001). These results were consistent with previous studies such **as Beydoğan et al** [24] (2.4 m/s VS 4.94 m/s and 18.7 Kpa VS 77.9 Kpa), **Baur et al** [14] (4.98 m/s VS 6.94 m/s and 93.54 kPa VS 152.88 kPa), and **Jiang et al** [13] (34.98 Kpa for plantar fasciitis group and 85.63 Kpa for healthy individuals).We also found a significant negative correlation between PF thickness and SWV and SWE similar to Gatz et al [25] (r = -0.421, p < 0.001, n = 82), while Baur **et al** did not observe any correlation (with an r2 value of 0.02 and p-value of 0.06) [14]. Our reported SWV cut-off value of 4.14 m/s was consistent with Gatz et al [25] , with an approximate stiffness cut-off value of 51.5 kPa (specificity of 80.95% and sensitivity of 79.31%), while Baur et al reported higher cut-off values of 6.16 m/s and 125.57 kPa [14]. These differences in cut-off values with Baur et al may be attributed to the limited number of cases in our study, as well as the differences in the numbers between cases and control groups in their study.

However, our study has some limitations, including the limited number of cases and the fact that it was a single observer evaluation. Therefore, larger studies with interobserver agreement assessment are recommended.

CONCLUSIONS

In conclusion, SWE has shown promising results in distinguishing between healthy and pathologic plantar fascia in association with B-mode ultrasound. SWE provides a quantitative assessment ofPF integrity and can distinguish between healthy and diseased fascia regardless of B-mode ultrasound appearance. Based on the results of this study, shear wave elastography can be considered an easy, simple, and effective additional method in diagnosing plantar fasciitis with B-mode ultrasound and can be helpful in the early diagnosis of the condition.

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Nil.

CONFLICTS OF INTEREST

There are no conflicts of interest

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