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REVIEW PAPER

An assessment of plantar fascia with ultrasound findings in patients with plantar fasciitis: a systematic review

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Abstract

Introduction Plantar fasciitis (PFS) is described by an intense pain over medial tubercle of calcaneus, increased with the first step after waking up, after rest and during weightbearing activity. It is the most common cause of plantar heel pain in adults with the prevalence estimated 10% of the general population. Ultrasound imaging is commonly being used to measure the PF thickness, evaluate the efficacy of different treatments and a guide therapeutic technique in patients with PFS. The objective of this study was to systematically review the studies that were previously published to evaluate the role of ultrasound in the assessment of PF in patients with PFS.

Methods A systematic search was carried out over the last 5 years from 2017 to 2022 on basis the following electronic databases: Science Direct, Scopus, Web of Science, Springer and PubMed. The keywords that used in the searching were: ultrasound, sonography, ultrasonography, plantar fasciitis, imaging of plantar fascia, physiotherapy of plantar fasciitis, interventional treatment of plantar fasciitis, randomized controlled trial of plantar fasciitis and interventional ultrasound. The review focused on the assessment of PF in patients with PFS underwent different interventions using B-mode, shear wave elastography (SWE) and color Doppler ultrasound.

Results During the search process, 1661 were recorded using the proper keywords from 2017 to 2022 in which 666 original articles were found after removing the review and duplicated articles. Of these, thirty articles met the inclusion criteria and included in this review. The articles have assessed the PF in patients with PFS under different conditions using different ultrasound modes. Twenty-six articles evaluated the effectiveness of different treatment on PF in patients with PFS using different ultrasound modes. In 8 of 26 articles, the ultrasound was used as both an assessment tool of PF and guide therapeutic technique in patients with PFS. In 18 articles, the ultrasound was used as only assessment tool to identify the PF thickness and its observation changes in patients with PFS. Four articles compared the PF thickness and its intrafascial changes between patients with PFS and healthy subjects.

Conclusion The ultrasound can be a reliable tool in assessment the effect of different interventions on PF by evaluating its thickness, echogenicity and stiffness changes in patients with PFS. There were different methods and treatments were used among the studies.

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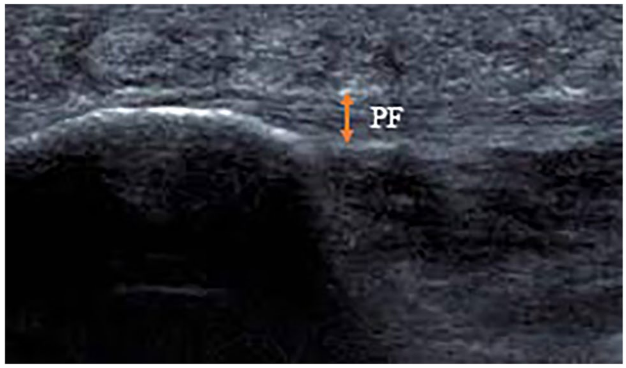
Graphical abstract



Keywords Ultrasound · Sonography · Plantar fasciitis · Imaging of plantar fascia · Physiotherapy of plantar fasciitis · Interventional treatment of plantar fasciitis

Introduction

Plantar fascia (PF) is the fibrous layer of connective tissue across the plantar surface of foot that has been an important role in ankle and foot biomechanics [1]. It consists of 3 main bands which are lateral, central and medial. The lateral band extends beneath the plantar surface of the abductor digiti quinti muscle and passes laterally with the posterior fascia and distally with the 5th metatarsophalangeal joint capsule. The central band is thickest and strongest one of the fascia, arising from the medial calcaneal tubercle and extending anteriorly to cover the plantar surface of the flexor digitorum brevis muscle. The medial band is the thinnest section, situated under the plantar surface of the abductor hallucis muscle, passing distally to the 1st metatarsophalangeal joint capsule and proximally to the flexor retinaculum of the foot [2, 3]. PF provides a static and dynamic support of the longitudinal arch foot, being as a dynamic shock absorber [4, 5].

Plantar fasciitis is commonly used to describe a plantar heel pain with inflammation of the PF at its origin, not to pain arising along the course of the fascia. In contrary, a substantial evidence of plantar fasciosis is associated with degenerative changes without inflammation [6]. Ledderhose disease, also known plantar fibromatosis, is a benign condition characterized by proliferation of fibrous tissue in form of nodules or cords in the PF, occasionally located on the medial and central bands of the fascia [7].

Nevertheless, there is a controversy regarding the appropriate term of plantar fasciitis, whether the disease should be referred to as “plantar fasciitis”, “plantar fasciosis” or “plantar heel pain”. Although the nature of plantar fasciitis can be either inflammatory or degenerative, imaging and histological findings confirm the hypothesis that “plantar fasciitis” is actually a degenerative disorder rather than inflammatory [4, 8]. Several studies; therefore, have used “plantar heel pain” as a general term [9–12]. In contrast, the recent trials and reviews [13] have regained to the most common clinical phrase of “plantar fasciitis”. Thus, we will use the term “plantar fasciitis (PFS)” in this review.

PFS is the most common cause of plantar heel pain in adults with the prevalence estimated 10% of the general population [14, 15]. Despite the pathogenesis of PFS is still ambiguous, the intrinsic muscle weakness, prolong standing, longtime walking and running, decreased elasticity of the plantar fascia, increased body mass index, reduced strength of gastrosoleus muscles, reduced dorsiflexion of ankle, leg length discrepancy and longitudinal arch deformity such as pes planus may increase the risk of PFS [16–18].

PFS is characterized by intense pain over the medial plantar aspect of the heel, sharpened with first step in the morning or after rest and increased during weightbearing activity [19–24].

The Cochrane review showed that an efficacy for any type of PFS treatments is not studied well [25]. Furthermore, treatment modalities and options for PFS remain inconsistent as well as the recommended methods of intervention are very limited [11, 13, 18, 26, 27]. There is a little evidence for using conservative treatment such as custom orthoses or prefabricated for long-term improvements in heel pain or disability [13, 28, 29] in spite of a recent trial revealed that short-term improvements in heel pain using full-length silicone insoles is considered as an initial line for PFS treatment [30]. In the light of that, a recent systematic review concluded that manual physiotherapy such as PF stretching and joint mobilization could reduce pain and stiffness, improve function and impairments. However, the optimum dosage of manual physiotherapy is still controversial [31]. In the same context, stretching of intrinsic foot muscle has been shown to be effective for improving heel pain and disability of PFS [32, 33].

As ultrasound is available, low-cost and comfortable for patients, it is superior to MRI in imaging the PF and diagnosis the PFS in many studies and as a guide therapeutic tool in patients with PFS [14]. This study was conducted to systematically review the previous studies using ultrasound as assessment tool in patient with PFS underwent different interventions.

Methodology

A searching was included the original articles published over the last 5 years from 2017 to 2022. The following electronic databases were depended: Science Direct, Scopus, Web of Science, Springer and PubMed. This systematic review was conducted according to the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) [34].

Search strategy

The following keywords: "ultrasound", "sonography", "ultrasonography", "plantar fasciitis", "imaging of plantar fascia", "physiotherapy of plantar fasciitis", "interventional treatment of plantar fasciitis", "randomized controlled trial of plantar fasciitis" and "interventional ultrasound" were used in the searching.

Inclusion criteria

The papers that have met the following criteria: (1) patients aged over 18 years. (2) patients with PFS, controlled (positive control) or healthy (negative control) groups for comparison. (3) randomized control trial or case–control design. (4) treatment of PFS with ultrasound assessment. (5) ultrasound was used in evaluation PF and surrounding tissues in patients with PFS. (6) the papers were written in English language. (7) original researches.

Data extraction

The articles were first checked based on titles and abstracts. If the title and abstracts were unclear, the full-length article was screened. The articles were chosen according to Critical Appraisal Skills Program (CASP, CASP UK, Oxford, UK) checklist. CASP results were summarized in Table 1. Two reviewers separately extracted the data from the final selected articles. If there was no agreement, the final decision was sought from the third reviewer.

Data collection process

During the search process, 4569 articles were found using proper keywords in which 1661 articles were found over the last five years. Of these, 666 articles were identified after removing the review and duplicated articles. Thirty- three of the 666 articles were relevant of this review. Two articles out of 33 articles are required subscribing to be able to download. One article was written in Chinese language except the abstract was written in English-language. Thus, thirty articles were analyzed and included in this search. Twenty-six of the 30 articles have assessed the effect of different treatments on PF in patients with PFS using both clinical examination and ultrasound imaging. Eight of 26 articles used ultrasound as both an assessment tool of PF and guide therapeutic in patients with PFS. Eighteen of the 26 articles used ultrasound as only assessment technique in diagnosis of PFS. The remaining 4 articles have compared PF thickness as well as intrafascial changes using different ultrasound modes between PFS patients and healthy subjects (Fig. 1). Twenty-nine of 30 articles have evaluated the PF thickness and its changes whereas only one article has only assessed the hypoechoic area within PF using B-mode ultrasound. In addition to measuring the thickness of the PF, there were 4 of the 30 articles have assessed the stiffness of PF using sonoelastography. In 3 of the 30 articles, the vascularity of PF was monitored using color Doppler ultrasound. In 7 articles, the echogenicity of PF was separately assessed on real-time B-mode. In one of the 30 articles, the fat pad thickness combined with PF thickness were measured.

Results

Six hundred sixty-six articles were found by the search process. Of these, thirty original articles [35–64] were closely related and included in this review. The articles have assessed the PF in patients with PFS under different conditions using different ultrasound modes from 2017 to 2022 (Table 2).

Twenty-six of the 30 articles [35, 36, 38, 41–58, 60–64] assessed the efficacy of different treatments on PF in patients with PFS using ultrasound (Table 3). As shown in Table 3, in 8 of the 26 articles, ultrasound was used as both an evaluating modality for assessment the PF thickness along with its alterations and a guided-treatment tool in patients with PFS who underwent the different interventions. In 5 of the 8 articles, the PF thickness was assessed alone using B-mode ultrasound. In 2 of the 8 articles, the combining PF thickness and echogenicity were monitored and recorded. In one article, the B-mode and color Doppler ultrasound evaluated the PF thickness, echogenicity and vascularity.

Table 1 Critical appraisal skills programme results

	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
Clearly focused research question	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Appropriate study designed	√	√	√	√	√	√	√	√	×	√	√	√	√	×	√
Appropriate recruitment and randomization	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Matched control	√	×	√	×	√	√	×	×	×	×	×	√	×	√	×
Test procedure clearly described	×	√	√	√	×	√	×	√	√	√	√	×	√	×	×
Appropriate outcomes used	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Outcomes accurately measured	√	×	√	√	√	√	√	√	×	√	√	×	√	×	√
Confounding factors accounted	√	√	×	×	×	√	√	×	×	√	√	×	√	×	√
Appropriate analysis	×	√	√	×	√	√	√	×	×	√	×	√	√	√	√
Accurate statistical results presented	√	√	×	×	×	√	√	×	×	√	√	√	×	√	√
Ability to generalized results	√	×	×	×	√	√	√	×	√	√	√	√	√	×	√
Interpretation related to existing evidence	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Total scores	10	10	9	8	9	12	11	8	6	12	11	9	11	7	11
	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
Clearly focused research question	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Appropriate study designed	√	√	√	√	√	√	√	√	√	×	√	√	√	×	√
Appropriate recruitment and randomization	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Matched control	√	×	×	×	×	×	×	×	×	√	×	×	×	√	×
Test procedure clearly described	√	×	×	×	×	√	×	√	√	√	√	×	√	√	×
Appropriate outcomes used	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Outcomes accurately measured	√	√	√	√	×	√	×	√	√	√	√	√	√	√	√
Confounding factors accounted	×	√	×	√	×	√	√	×	√	×	×	√	√	√	×
Appropriate analysis	√	√	√	√	√	√	×	√	×	√	√	√	√	√	√
Accurate statistical results presented	×	√	√	√	√	√	×	√	×	√	√	√	√	√	√
Ability to generalized results	√	√	×	×	√	√	√	×	×	√	√	√	√	√	√
Interpretation related to existing evidence	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Total scores	10	10	8	9	8	11	7	9	8	10	10	10	11	11	9

In other 18 articles, ultrasound was used as only the assessment tool for imaging PF changes in patients with PFS before and after treatment. In 12 of the 18 articles have evaluated the PF thickness alone using B-mode ultrasound. In 4 more articles, the PF thickness along with its observation changes such as echogenicity, stiffness, vascularity or morphology were evaluated using B-mode, color Doppler or SWE. In another article, the heel fat pad thickness combined with PF thickness have been measured and recorded. The remaining one article has only investigated the hypoechoic area changes within and around PF and the size of area was recorded at pre and post intervention.

Four of the 30 articles [37, 39, 40, 59] were carried out to evaluate sonographically the PF thickness as well as fascial alterations between patients with PFS and healthy subjects that have no underwent therapeutic interventions (Table 4). One of the 4 articles has measured the PF thickness without evaluation of the fascial changes. In two more articles, combining the PF thickness and fascial stiffness were assessed using B-mode and SWE, respectively. The remaining one article was carried out to evaluate the PF thickness, stiffness and hyperemia using B-mode, SWE and color Doppler ultrasound, respectively.

Nine of the 30 articles [35, 37, 39, 40, 46, 48, 50, 59, 63] have included matched control groups. As outlined in Table 5, 7 of the 9 articles have included healthy subjects with no intervention (negative control). 4 of the 7 articles were carried out as case–control studies design having only two groups; PFS group with no intervention and healthy subjects. Other three were experimental studies as follows: one study included three groups; two of them with PFS received either treatment group or sham-treatment group (positive controls) and one group was healthy. Two studies had two groups in which one group with PFS was subjected to treatment whereas other had no PFS and had no exposure to treatment. The remaining two of the 9 studies were designed as experimental studies having two groups with PFS; one group underwent the treatment "study group" and other was subjected to sham-treatment.

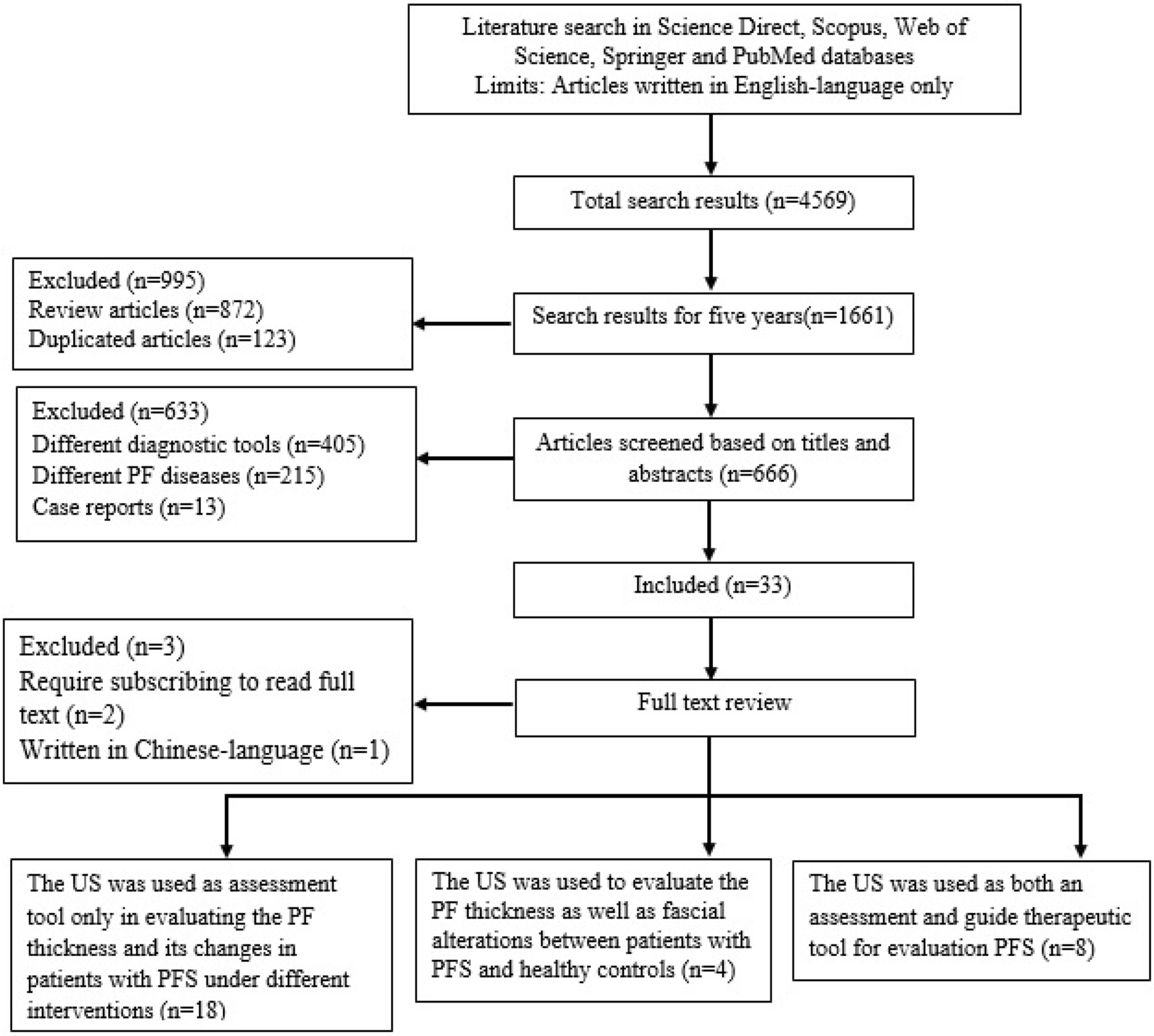


Fig. 1 Flow diagram of the study. *PF* plantar fascia, *PFS* plantar fascitiis, *US* ultrasound

Discussion

This study was carried out to systematically review published articles that assessed the PF in patients with PFS using ultrasound under different conditions from 2017 to 2022 (Table 2). Thirty studies conducted to evaluate the PF alterations and its thickness in patients with PFS underwent different intervention or compared to those with healthy subjects using different ultrasound modes such as B-mode, color Doppler or SWE. In these studies, ultrasound was used as assessment modality alone or combined with guide therapeutic for evaluation for evaluation the PFS. Based on the results of this systematic review, using ultrasound as assessment tool was available, low cost, safe and reliable in evaluating of PF changes.

In this review, all studies found that the PF thickness and/or fascial alterations was reliable in diagnosis of the PFS. In meanwhile, several differences of methods were observed among the previous studies during this review. The major differences were noted in sample size, study design, type of intervention, measurement tool and methods, sonographic features of PF (thickness, echogenicity, vascularity or stiffness) and follow-up period. In this review, majority of the reviewed articles showed that a monitoring of PF thickness and intrafascial changes are considered as a key role in the assessment of PFS using ultrasound particularly during follow-up treatment.

Table 2 Overview of studies conducted on the evaluation of PF under different conditions using US

References	Sample size	Des	objective	Outcome measures	Position for assessment	Measurement tools	Type of intervention	Site of measurement	Follow-up	Conclusion
[35]	22 pts (10 ESWT vs 12 sham-ESWT)	RCT	To investigate the efficacy and tolerability of ESWT in patients with PFS in axSpA	Pain, foot function, PF thickness and morphology	Prone with full knee extension and 90° dorsiflexion of the ankle	B-mode US, VAS, heel pressure algometry, FFI	ESWT vs sham-ESWT	At 5 mm distal to the calcaneal insertion from the medial aspect	at baseline, 1, 4, 8 weeks after the last therapy	ESWT was a safe and tolerable physical therapy to improve chronic heel pain due to PFS in patients with axSPA with no significant effect on PF
[36]	59 pts (29 rESWT vs 30 DPI)	RCT	To compare the effects of US-guided DPI with rESWT in the treatment of chronic PFS	Pain intensity, daily life and exercise activities, PF thickness	NR	B- mode US, VAS and FAAM	rESWT vs DPI	At the calcaneus insertion	At baseline, 6 weeks and 12 weeks after the treatment	DPI could reduce pain and PF thickness compared to rESWT in patients with PFS
[37]	39 pts (19 PFS pts vs 20 healthy controls)	CC	To compare stiffness of PF between patients with PFS and healthy subjects using SWE and to correlate SWE values with clinical scores	PF thickness, SWV and stiffness, clinical scores	Prone position with foot hanging over the end of table	B-mode US, SWE, VAS, FFI	NA	1 cm distally from the calcaneal insertion	NA	SWE allows quantitative evaluation of the elasticity of the PF and can show PFS alterations. SWE shows a strong correlation with clinical scores
[38]	40 pts (20 DPI and 20 CSI)	RCT	To valuate and compare the effect of ultrasound-guided DPI vs CSI in chronic PFS	Pain, foot function, PF thickness and area of hypoechogenic-ity	Prone position with the ankle at 90°	NRS, B-mode US, FAAM-A FAAM-S)	DPI vs CSI	Both PF thickness and area of hypoechogenici-ty at the insertion and 1 cm distal to the insertion zone	At 2 and 12 weeks after injection	CSI may reduce pain, PF thickness better early, but both CSI and DPI have similar effects for a few months (up to 12 weeks)
[39]	108 pts (87 pts and 21 healthy subjects)	CC	To evaluate the PF between healthy subjects and PFS patients by SWE with correlation to B-mode and CDUS and to establish cut-off values	PF thickness, vascularity grades, SWV and stiffness	NR	B-mode, color Doppler US and SWE	NA	Thickness was measured at calcaneus insertion. ROI was set within the thickest part of the PF. CDUS was applied on whole fascia	NA	SWE was able to Quantitatively assess the PF stiffness, which reduces in patients with PFS. PF was thickened in PFS compared to healthy fascia No correlation of vascularity was found between both groups

Table 2 (Continued)

References	Sample size	Des	objective	Outcome measures	Position for assessment	Measurement tools	Type of intervention	Site of measurement	Follow-up	Conclusion
[40]	82 pts (39 PFS, 23 unilateral healthy foot and 20 bilateral healthy feet)	CC	To determine the diagnostic potential of SWE and the correlation of clinical scores to SWE values	PF thickness, clinical scores, SWV and stiffness	Prone position with the foot hanging over the edge of table	B-mode, SWE, AOFAS and FFI	NA	At the calcaneus insertion; + 1 cm distal of the calcaneus and central part of the calcaneus	NA	SWE appears to enhance the diagnostic accuracy in patients with PFS as compared with B-mode US
[41]	38 (19 PDRN and 19 CSI)	RCT	To compare the efficacy and safety of PDRN injection and CSI for PFS	Pain, thickness and echogenicity of PF	NR	B-mode US, VAS and MOXFQ	PDRN injection vs CSI	NR	VAS at baseline; 1, 2, 6 and 24 weeks and 6 ms post-treatment MOXFQ at baseline,6 weeks and 6 ms after treatment PF thickness at baseline, 6 ms after treatment	CSI has a positive clinical effect at short-term follow-up as compared to PDRN. No differences between PF thickness and echogenicity was found between two groups
[42]	80 pts (40 ESWT and 40 CSI)	RCT	To compare and evaluate the therapeutic effects of ultrasound-guided CSI vs medium frequency ESWT in the treatment of PFS	Pain, foot function, PF thickness	NR	B-mode US, VAS, FFI and HTI score	ESWT vs CSI	At insertion of the fascia into the calcaneal tubercle	At baseline, 3, and 6 ms after treatment	The patients were not satisfied with the rESWT technique if it was applied as a primary treatment protocol
[43]	22 pts (one group received ESWT)	LF	To evaluate the changes in PF stiffness pre and post ESWT in patients with PFS	Pain, PF thickness and stiffness	Prone position with 90° of knee flexion in the neutral ankle position	VAS, B-mode US and SEG	ESWT	NR	At baseline, at 1 wk, 1 m, 3 m, 6 m, and 12 m after ESWT	The heel pain and PF thickness reduced gradually over 12 ms after ESWT. The PF stiffness reduced during the first wk and increased afterthat; at the 12 ms follow-up, stiffness was higher before ESWT

Table 2 (Continued)

References	Sample size	Des	objective	Outcome measures	Position for assessment	Measurement tools	Type of intervention	Site of measurement	Follow-up	Conclusion
[44]	75 pts (38 HA and 37 CSI)	RCT	To assess the effectiveness of HA injection in reducing the symptoms of PFS compared to CSI	Pain and PF thickness, foot function and Foot and Ankle Ability	Prone position, 90° knee flexion with ankle in neutral position	B-mode US, VAS, FAAI, PPT and FFI	US-guided injection of HA vs CSI	NR	at baseline, 6 weeks and 24 weeks after the injection	Both CSI and HA resulted a better outcomes for PF as well as reducing pain and improving function
[45]	102 pts (51 HILT and 51 LLLT)	RCT	To evaluate and compare the efficacy of HILT and LLLT for PFS	Pain and PF thickness	Prone position with the feet hanging in end of table	B-mode, VAS and pressure algometry	HILT vs LLLT	At the calcaneus insertion zone	At baseline, 0–3 weeks and 3–4 weeks follow-up	There was no significant effect between both groups
[46]	60 pts (30 DP and 30 controls given saline)	RCT	To evaluate the therapeutic effects of DP in the treatment of PFS compared to control group	Pain, foot disability, PF thickness and echogenicity	Prone with the ankle placed in the neutral position	B-mode, VAS-A, VAS-R and FFI	DP vs control group (given saline)	NR	At baseline, at 7 and 15 weeks post-treatment	Improvement in PF thickness, foot function and pain was significantly higher in DP group than in control group
[47]	44 pts (22 MPC vs 22MPC + SE)	RCT	To assess the effect of MPC and MPC + PF-SE on heel pain and PF thickness in treatment of PFS	Pain and PF thickness	Prone, foot hanging over the edge of table with ankle in neutral position	B-mode US and VAS	MPC only vs MPC + PF-SE	At the calcaneus insertion and within 5 mm from calcaneus insertion	At baseline, 4 weeks post-treatment	MPC can reduce the PF thickness but MPC combined with PF-SE is not better than MCP only in reduction heel pain and PF thickening
[48]	94 (44 pts and 50 healthy controls)	RCT	To determine the efficacy of high-resolution US in the evaluation of PF in patients with heel pain	PF thickness	Prone with foot hanging over the edge of the table with ankle in dorsiflexion	B-mode	NA	Within 1 cm from calcaneal attachment	NA	PFS can be easily diagnosed by US with PF > 4 mm in thickness
[49]	96 pts (49 ESWT vs 47 local CSI)	Block RCT	To evaluate the therapeutic clinical effects of local CSI and ESWT in treatment of PFS	Pain, disability and PF thickness	NR	B-mode, VAS and FFI	local CSI vs ESWT	At point where the PF crosses the anterior aspect of the inferior border of the calcaneus	At baseline, 1 m, 3 ms and 6 ms	Both ESWT and local CSI resulted in clinical improvement and PF thickness at follow-up but foot function have no significant difference between both groups

Table 2 (Continued)

References	Sample size	Des	objective	Outcome measures	Position for assessment	Measurement tools	Type of intervention	Site of measurement	Follow-up	Conclusion
[50]	120 (60 EA, 30 SA, 30 controls)	RCT	To compare the efficacy of EA and SA versus waitlist control for improving the pain in patients with chronic PFS	Pain, disability, PF thickness	Prone position	B-mode, VAS, PPT, AROM and FAAM	EA vs SA vs non-treatment control	At the thickest portion closest to the calcaneal insertion in its medial tuberosity	At baseline, 4 weeks, with a 12-weeks follow-up	Assessment of PF thickness may detect the anatomical changes that occur in the PF after acupuncture
[51]	78 pts (36 KT vs 42 ESWT)	RCT	To compare the efficacy of KT and ESWT in the management of PFS	Pain, foot function and PF thickness, heel fat pad thickness	Prone position with an ankle in neutral position	B-mode US, VAS and FFI	KT vs ESWT	NR	At baseline and 6 weeks after treatment	Both KT and ESWT reduced the pain levels and improved quality of life in PFS patients. In both groups, the PF thickness has decreased whereas fat pad thickness has increased; however, the differences was not significant
[52]	33 patients	Pivotal clinical trial	To assess the efficacy, safety and tolerability of ITU combined with standard-of-care in the management of chronic PFS	Pain, foot function, level of activity Hypoechoic area changes	NR	B-mode US-SROMs, VAS, FFI and FAAM	standard conservative care alone and Combining with ITU	NR	At baseline and 4, 8, 12 and 26 weeks after treatment	ITU has reported to be effective, safe, and well tolerated option Hypoechoic areas were gradually decreased in size at follow-up
[53]	40 pts (20 PRP vs 20 CSI)	CNP	To evaluate the efficacy and imaging changes between PRP and CSI in the treatment of PFS	Pain, PF thickness, echogenicity, vascularity and function	NR	VAS, AOFAS, B-mode US, MRI	PRP vs CSI	NR	US was done at baseline, 3 and 6 ms MRI was done at baseline and 6 ms, VAS and AOFAS results was evaluated at baseline, 6 and 12 ms after treatment	The PF thickness has significantly decreased at 3-ms follow-up in both groups. The echogenicity and vascularity have significantly reduced at 3 and 6-ms follow-up in PRP group only. Thus, PRP injection is a safe and more efficient than CSI in treatment of PFS

Table 2 (Continued)

References	Sample size	Des	objective	Outcome measures	Position for assessment	Measurement tools	Type of intervention	Site of measurement	Follow-up	Conclusion
[54]	60 pts (30 PRP vs 30 CSI)	RCT	To evaluate the effectiveness of local injection of PRP and CSI in the treatment of chronic PFS	Pain, PF thickness and function	NR	B-mode US, VAS and AOFAS score	PRP vs CSI	NR	At baseline, 6 weeks, 3 ms and 6 ms follow-up after injection	Over the time, PRP local injection was an effective treatment in improving the pain levels, foot function and PF thickness compared to CSI
[55]	34 patients (17 ESWT vs 17 LLLT)	RCT	To compare the efficacy of ESWT and LLLT on PF thickness, heel pain, and foot functions in patients with PFS	Pain, foot function and PF thickness	Prone position with knees fully extended and ankles in a neutral position	B-mode US, VAS and FFI	ESWT vs LLLT	At the point where PF is inserted into medial calcaneal tubercle	at baseline, immediate after the treatment, and after 1 m	Both ESWT and LLLT have a clinical improvement such as reducing pain and improving foot functions as well as reducing PF thickness in patients with PFS
[56]	90 patients 30 ST 31 CSI 29 combined ST + CSI	RCT	To evaluate the effects of ST, local CSI, or combined ST and CSI on chronic PFS	Pain, foot function and PF thickness	Prone with 90º flexed, foot hanging on the edge of table in neutral position	B- mode US, VAS and FFI	ST, CSI and combined ST + CSI	NR	-VAS and FFI at baseline and 6 ms post therapy -US at baseline, 1,2,3,6, 12 ms post therapy	The combination of CSI and ST had a superior effect on pain, foot function and PF thickness at all time points in patients with PFS as compared with either CSI or ST treatment
[57]	30 pts (15 ozone injection) vs 15 CSI)	RCT	To determine the effects of ozone injection and CSI in the treatment of chronic PFS	Pain, activity and PF thickness	Prone position with their feet hanging over the edge of the table	VAS, B-mode and FAAM	Ozone (O2- O3) injection vs CSI	At insertion and 1 cm distal to its insertion into the medial calcaneal tubercle	At baseline, 2 and 12 weeks after injection	Ozone injection and CSI were effective in long term and short term, respectively. Both Ozone injection and CSI were observed to reduce pain and PF thickness and enhance foot function

Table 2 (Continued)

References	Sample size	Des	objective	Outcome measures	Position for assessment	Measurement tools	Type of intervention	Site of measurement	Follow-up	Conclusion
[58]	64 pts (36 PRP injection vs 28 KT)	RCT	To compare the effectiveness of PRP vs KT with phonophoresis in the treatment of chronic PFS	Disability and activity and PF thickness	Prone position with ankle in a neutral position	NRS, FFI and B-mode US	PRP vs KT with phonophores-is	At calcaneal attachment	NRS at baseline, 2,6,12 and 24 weeks FFI and US at baseline, 6,12 and 24 weeks	PRP was better in relief pain in short time follow-up whereas it is better in improving NRS, functional status and PF thickness in long time follow-up compared to KT with phonophoresis
[59]	40 subjects (20 PFS pts vs 20 controls)	CC	To determine the influence of MTP joint extension on PF thickness in healthy subjects compared to those unilateral PFS	PF thickness measured at rest, 30° of MTP joints extension and maximal possible extension	Prone with the examined foot over the edge of the table and the ankle in neutral position	B-mode	NA	At the anterior margin of the calcaneus	NA	MTP joint position was effective in the measurement of PF thickness
[60]	110 pts (55 ESWT vs 55 CSI)	RCT	To assess efficacy of CSI and ESWT in PFS patients to determine the correlation between clinical outcomes and the PF thickness	Pain and PF thickness	NR	VAS, 100-points scoring systems and B-mode US	ESWT vs CSI	At insertion and 5 mm distal to calcaneus tuberosity	At baseline, 4 and 12 wk	The positive changes in PF after ESWT treatment is given better clinical outcomes in PFS patients
[61]	80 pts(40 PRP vs 40 CSI)	RCT	To evaluate the efficacy of local CSI vs PRP in the management of PFS	Pain, activity, foot function and PF thickness	NR	VAS, modified Roles and Maudsley score, FAI, AOFAS, B-mode US	PRP vs CSI	NR	At baseline at 1 m, 3 ms, and 6 ms after treatment	Both CSI or PRP was equally effective on clinical outcomes and PF thickness in patients with PFS
[62]	72 pts (36 rESWT vs 36 CSI)	RCT	To compare the clinical and sonographic effects of rESWT and CSI in patients with PFS	Pain, function and PF thickness and echogenicity	NR	VAS, FFI, HTI score and B-mode US	rESWT vs CSI	At the point where PF inserted into calcaneal tuberosity	at baseline and 1, 3, and 6 ms after treatment	rESWT noted to be superior to CSI in improving clinical outcomes and PF changes due to its long-term action

Table 2 (Continued)

References	Sample size	Des	objective	Outcome measures	Position for assessment	Measurement tools	Type of intervention	Site of measurement	Follow-up	Conclusion
[63]	60 pts (40 ESWT vs 20 controls)	LF	To evaluate the efficacy of ESWT in the treatment of chronic PFS in patients with calcaneal spur using US	Pain, function and PF thickness	Prone with toes placed over the end of the examination table	VAS, Maudsley score, x-ray and B-mode US	ESWT	At 2 cm distal to the calcaneal insertion	At baseline and 8 weeks after treatment	PF has thickened in calcaneal spur patients. ESWT found to decrease the PF thickness and improve pain and function significantly
[64]	30 pts (15 PRP vs 15 dry needling)	RCT	To compare the treatment effects of PRP and dry needling on chronic PFS	Foot function, PF thickness, echogenicity and vascularity	NR	FFI, B-mode and power Doppler US	PRP vs dry needling of myofascial meridian trigger points	NR	At baseline, 6 and 12 weeks after treatment	A clinical and US improvement were observed in PRP group at 12-weeks follow-up in patients with chronic PFS

PF plantar fascia, *PFS* plantar fasciitis, *FAAM* Foot and Ankle Ability Measure, *FAAM-A* Foot and Ankle Ability Measure-Activity, *FAAM-S* Foot and Ankle Ability Measure-Sport, *rESWT* radial extracorporeal shock wave therapy, *VAS* visual analog scale, *FFI* Foot Function Index, *RCT* Randomized Controlled Trail, *DPI* Dextrose Prolotherapy Injection, *CSI* Corticosteroid Injection, *NRS* Numeric Rating Scale, *US* ultrasound, *PDRN* polydeoxyribonucleotide, *MOXFQ* Manchester-Oxford Foot Questionnaire, *HTI* Heel Tenderness Index, *LF* longitudinal follow-up, *SEG* Strain Elastography, *wk(s)* week(s), *m(s)* month(s), *HA* hyaluronic acid, *FAAI* Foot Ankle Ability Index, *PPT* pressure pain threshold, *HILT* high-intensity laser therapy, *LLLT* low-level laser therapy, *SE* stretching exercises, *SA* sham acupuncture, *AROM* Ankle Range Of Motion, *EA* electroacupuncture, *KT* kinesiotaping, *ITU* Intense Therapeutic Ultrasound, *SROMs* subject-reported outcome measure, *CNP* comparative non-randomized prospective, *MRI* magnetic resonance imaging, *AOFAS* American Orthopedic Foot and Ankle Society, *ST* strength training and stretching, *RPS* randomized pilot study, *FAI* foot and ankle outcome instrument, *MPC* monophasic pulsed current, *CC* case–control, *NR* not reported, *NA* not applicable, *SWV* shear wave velocity, *axSPA* Axial spondyloarthritis, *ROI* region of interest, *Pts* patients

Assessment of PF thickness and fascial alterations after different interventions

As presented in Table 3, there 26 studies have sonographically assessed the different interventions such as injection, ESWT, manual physiotherapy, high-intensity laser therapy (HILT), low-level laser therapy (LLLT), Electroacupuncture (EA), Kinesiotaping (KT), Intense Therapeutic Ultrasound (ITU) and Monophasic Pulsed Current (MPC) in patients with PFS.

In 8 out of the 26 studies [36, 38, 42, 44, 57, 58, 62, 64], the ultrasound was used as assessment tool combined with guided treatment injection in PFS patients. These studies that were designed as randomized controlled trials showed that the use of ultrasound to guide injection and evaluate the PF changes was an effective modality. The trials assessed the efficacy of ultrasound-guided injection of different treatments in patients with PFS. All outcome measures were assessed at baseline and after treatments. The primary outcomes measured were as follows: pain by visual analog scale (VAS), daily life and exercise activities by Foot and Ankle Ability Measure (FAAM), and foot function by foot function index (FFI). The secondary outcomes measured by ultrasound were PF thickness alone or combined with PF echogenicity or vascularity or both. For example, five studies [36, 42, 44, 57, 58] assessed the PF thickness alone using B-mode ultrasound at baseline and at follow-ups interventions. Other two studies [38, 62] assessed both PF thickness and fascial echogenicity in order to evaluate the effects of treatments in patients with PFS. One study [64] investigated combining PF thickness, echogenicity and vascularity using B-mode and color Doppler ultrasound in patients with PFS at pre and post intervention. All these studies concluded that ultrasound was an effective, safe, tolerable and accurate to use as a guide-therapeutic and assessment tool in evaluation of patients with PFS.

The remaining 18 articles used the ultrasound with different modes as only assessment tool to evaluate the improvements of PF thickness alone or combined with intrafascial or perifascial changes in patients with PFS undergoing different interventions. In which four articles [35, 41, 43, 53] assessed the combining PF thickness and its fascial changes using different ultrasound modes. For example, a longitudinal follow-up study [43] evaluated the PF thickness and stiffness pre and post extracorporeal shockwave therapy (ESWT) in 22 patients with PFS. The PF thickness and stiffness were evaluated by B-mode and strain elastography, respectively. The PF changes was evaluated at baseline and at 1-week, 1-month, 3-month, 6-month, and 12-month e after ESWT. The study concluded that PF stiffness reduced at the first week and then increased at the 12-months after treatment. However, the PF thickness decreased gradually during 12-months follow-up intervention.

In single-center, non-randomized prospective study [53], forty patients with PFS received either platelet-rich plasma (PRP) injection (20 patients) or corticosteroid injection (CSI) (20 patients). The imaging assessment of the outcome measures were performed by ultrasound and magnetic resonance imaging (MRI). However, the ultrasound assessed the following outcome measures at baseline, 3 and 6 months; PF thickness and echogenicity by B-mode and neovascularization by color Doppler. The authors concluded that PF thickness has significantly reduced at 3-months after injection in both groups. The echogenicity and vascularity, however; have significantly reduced at 3- and 6-months after PRP injection only.

A double-blinded, randomized clinical trial [41] included 39 patients with PFS divided into two groups: 39 patients received polydeoxyribonucleotide (PDRN) versus 39 patients CSI. The outcomes measured by ultrasound included PF thickness and fascial echogenicity. The sonographic outcomes were evaluated at baseline and 6 months after injection. The studies concluded that PF echogenicity was significantly different within CSI group during follow-up injection whereas PF thickness did not differ intragroups. However, there were no significant different of PF thickness and echogenicity between both groups.

A prospective double-blinded randomized controlled [35] investigated the PF thickness and morphology of 22 patients divided into two groups: ESWT group and sham-ESWT group. The PF thickness and morphology of PF included (echogenicity, convexity and perifascial fluid) were assessed at baseline, 1, 4, 8 weeks after treatment. The trial revealed no changes in PF thickness pre and post intervention in both groups. However, the authors showed that alterations in the PF morphology such as decreased hypoechogenicity, increased convexity and presence perifascial fluid are considered as sonographic features of PFS.

A single-center, single-blinded, randomized clinical trial [51] conducted on 78 patients with PFS divided into two groups; 36 patients were subjected to Kinesiotaping (KT) and 42 patients were exposure to ESWT. The outcomes measured by ultrasound were PF thickness and heel fat pad thickness. The findings were monitored at baseline and 6-weeks after treatments. In both groups, the study concluded that PF thickness decreased after treatment whereas heel fat pad thickness increased.

A another single-blinded, pivotal clinical trial study [52] conducted on 33 patients with chronic PFS. The patients were exposure to intense therapeutic ultrasound (ITU) combined with standard conservative treatment at 0 (baseline), 4, 8, 12 and 26 weeks after treatments. The hypoechoic areas were only outcome measured by ultrasound. Perifascial and intrafascial hypoechoic areas/lesions were diagnosed in all patients and the size of area/lesion was measured at each follow-up visit. The study findings revealed that hypoechoic areas decreased gradually during follow-up period.

In the remaining 12 studies [45–50, 54–56, 60, 61, 63], different interventions were applied on different trials and different follow-up periods. In all these trials, the outcome measured by ultrasound was only PF thickness. The changes in PF thickness were different among the studies. For example, Naruseviciute and Kubilius [45], showed that the difference of PF thickness between groups after intervention was not significant. Mansiz-Kaplan et al. [46] concluded that there were improvements in PF thickness in intra – and intergroups after treatments. Xu et al. [49] found a significant improvement of PF thickness at 3- months in one group and 3- and 6- months in other group compared to the baseline values. Furthermore, a significant reduction in PF thickness was found between groups at 6-months follow-up. The remaining 8 articles stated that PF thickness was significantly improved between groups after treatments in PFS patients.

Evaluating of PF thickness and its alterations between PFS patients and healthy controls with no intervention

As shown in Table 4, Four studies [37, 39, 40, 59] compared the PF changes including thickness, stiffness and neovascularization between patients with and without PFS. Baur et al. [39] evaluated 108 unilateral PF including 87 with PFS and 21 healthy. The PF thickness, stiffness and vascularity were assessed in all subjects using B-mode, SWE and color Doppler, respectively. The study showed that shear wave velocity (SWV) and stiffness were significantly higher in healthy subjects than in patients. SWV and stiffness had sensitivity 79.31% and 80.46%, respectively; whereas had specificity 80.95% for both. The PF thickness was observed to be thicker in PFS patients than in healthy controls. There was no correlation between color Doppler and PF thickness with SWE measurements. Therefore, the study concluded that SWE represents an independent parameter in detecting PFS.

Table 3 Details of studies using US evaluating the PF in patients with PFS underwent different interventions

References	Sample size	Des	objective	Outcome measures	Position for assessment	Measurement tools	Type of intervention	Site of measurement	Follow-up	Conclusion
[35]	22 pts (10 ESWT vs 12 sham-ESWT)	RCT	To investigate the efficacy and tolerability of ESWT in patients with PFS in axSpA	Pain, foot function, PF thickness and morphology	Prone with full knee extension and 90° dorsiflexion of the ankle	B-mode US, VAS, heel pressure algometry, FFI	ESWT vs sham-ESWT	At 5 mm distal to the calcaneal insertion from the medial aspect	At baseline, 1, 4, 8 weeks after the last therapy	ESWT was a safe and tolerable physical therapy to improve chronic heel pain due to PFS in patients with axSPA with no significant effect on PF
[36]	59 pts (29 rESWT vs 30 DPI)	RCT	To compare the effects of US-guided DPI with rESWT in the treatment of chronic PFS	Pain intensity, daily life and exercise activities, PF thickness	NR	B- mode US, VAS and FAAM	rESWT vs DPI	At the calcaneus insertion	At baseline, 6 weeks and 12 weeks after the treatment	DPI could reduce pain and PF thickness compared to rESWT in patients with PFS
[38]	40 pts (20 DPI and 20 CSI)	RCT	To valuate and compare the effect of ultrasound-guided DPI vs CSI in chronic PFS	Pain, foot function, PF thickness and area of hypoechogenic-ity	Prone position with the ankle at 90°	NRS, B-mode US, FAAM-A FAAM-S)	DPI vs CSI	Both PF thickness and area of hypoechogenici-ty at the insertion and 1 cm distal to the insertion zone	At 2 and 12 weeks after injection	CSI may reduce pain, PF thickness better early, but both CSI and DPI have similar effects for a few months (up to 12 weeks)
[41]	38 (19 PDRN and 19 CSI)	RCT	To compare the efficacy and safety of PDRN injection and CSI for PFS	Pain, thickness and echogenicity of PF	NR	B-mode US, VAS and MOXFQ	PDRN injection vs CSI	NR	VAS at baseline; 1, 2, 6 and 24 weeks and 6 ms post-treatment MOXFQ at baseline,6 weeks and 6 ms after treatment PF thickness at baseline, 6 ms after treatment	CSI has a positive clinical effect at short-term follow-up as compared to PDRN. No differences between PF thickness and echogenicity was found between two groups
[42]	80 pts (40 ESWT and 40 CSI)	RCT	To compare and evaluate the therapeutic effects of ultrasound-guided CSI vs medium frequency ESWT in the treatment of PFS	Pain, foot function, PF thickness	NR	B-mode US, VAS, FFI and HTI score	ESWT vs CSI	At insertion of the fascia into the calcaneal tubercle	At baseline, 3, and 6 ms after treatment	The patients were not satisfied with the rESWT technique if it was applied as a primary treatment protocol

Table 3 (Continued)

References	Sample size	Des	objective	Outcome measures	Position for assessment	Measurement tools	Type of intervention	Site of measurement	Follow-up	Conclusion
[43]	22 pts (one group received ESWT)	LF	To evaluate the changes in PF stiffness pre and post ESWT in patients with PFS	Pain, PF thickness and stiffness	Prone position with 90° of knee flexion in the neutral ankle position	VAS, B-mode US and SEG	ESWT	NR	At baseline, at 1 wk, 1 m, 3 m, 6 m, and 12 m after ESWT	The heel pain and PF thickness reduced gradually over 12 ms after ESWT. The PF stiffness reduced during the first wk and increased afterthat; at the 12 ms follow-up, stiffness was higher before ESWT
[44]	75 pts (38 HA and 37 CSI)	RCT	To assess the effectiveness of HA injection in reducing the symptoms of PFS compared to CSI	Pain and PF thickness, foot function and Foot and Ankle Ability	Prone position, 90° knee flexion with ankle in neutral position	B-mode US, VAS, FAAI, PPT and FFI	US-guided injection of HA vs CSI	NR	At baseline, 6 weeks and 24 weeks after the injection	Both CSI and HA resulted a better outcomes for PF as well as reducing pain and improving function
[45]	102 pts (51 HILT and 51 LLLT)	RCT	To evaluate and compare the efficacy of HILT and LLLT for PFS	Pain and PF thickness	Prone position with the feet hanging in end of table	B-mode, VAS and pressure algometry	HILT vs LLLT	At the calcaneus insertion zone	At baseline, 0–3 weeks and 3–4 weeks follow-up	There was no significant effect between both groups
[46]	60 pts (30 DP and 30 controls given saline)	RCT	To evaluate the therapeutic effects of DP in the treatment of PFS compared to control group	Pain, foot disability, PF thickness	Prone with the ankle placed in the neutral position	B-mode, VAS-A, VAS-R and FFI	DP vs control group (given saline)	NR	At baseline, at 7 and 15 weeks post-treatment	Improvement in PF thickness, foot function and pain was significantly higher in DP group than in control group
[47]	44 pts (22 MPC vs 22MPC + SE)	RCT	To assess the effect of MPC and MPC + PF-SE on heel pain and PF thickness in treatment of PFS	Pain and PF thickness	Prone, foot hanging over the edge of table with ankle in neutral position	B-mode US and VAS	MPC only vs MPC + PF-SE	At the calcaneus insertion and within 5 mm from calcaneus insertion	At baseline, 4 weeks post-treatment	MPC can reduce the PF thickness but MPC combined with PF-SE is not better than MCP only in reduction heel pain and PF thickening
[48]	94 (44 pts and 50 healthy controls)	RCT	To determine the efficacy of high-resolution US in the evaluation of PF in patients with heel pain	PF thickness	Prone with foot hanging over the edge of the table with ankle in dorsiflexion	B-mode	NA	Within 1 cm from calcaneal attachment	NA	PFS can be easily diagnosed by US with PF > 4 mm in thickness

Table 3 (Continued)

References	Sample size	Des	objective	Outcome measures	Position for assessment	Measurement tools	Type of intervention	Site of measurement	Follow-up	Conclusion
[49]	96 pts (49 ESWT vs 47 local CSI)	Block RCT	To evaluate the therapeutic clinical effects of local CSI and ESWT in treatment of PFS	Pain, disability and PF thickness	NR	B-mode, VAS and FFI	local CSI vs ESWT	at point where the PF crosses the anterior aspect of the inferior border of the calcaneus	At baseline, 1 m, 3 ms and 6 ms	Both ESWT and local CSI resulted in clinical improvement and PF thickness at follow-up but foot function have no significant difference between both groups
[50]	120 (60 EA, 30 SA, 30 controls)	RCT	To compare the efficacy of EA and SA versus waitlist control for improving the pain in patients with chronic PFS	Pain, disability, PF thickness	Prone position	B-mode, VAS, PPT, AROM and FAAM	EA vs SA vs non-treatment control	At the thickest portion closest to the calcaneal insertion in its medial tuberosity	At baseline, 4 weeks, with a 12-weeks follow-up	Assessment of PF thickness may detect the anatomical changes that occur in the PF after acupuncture
[51]	78 pts (36 KT vs 42 ESWT)	RCT	To compare the efficacy of KT and ESWT in the management of PFS	Pain, foot function and PF thickness, heel fat pad thickness	Prone position with an ankle in neutral position	B-mode US, VAS and FFI	KT vs ESWT	NR	At baseline and 6 weeks after treatment	Both KT and ESWT reduced the pain levels and improved quality of life in PFS patients. In both groups, the PF thickness has decreased whereas fat pad thickness has increased; however, the differences was not significant
[52]	33 patients	Pivotal clinical trial	To assess the efficacy, safety and tolerability of ITU combined with standard-of-care in the management of chronic PFS	Pain, foot function, level of activity Hypoechoic area changes	NR	B-mode US-SROMs, VAS, FFI and FAAM	standard conservative care alone and Combining with ITU	NR	At baseline and 4, 8, 12 and 26 weeks after treatment	ITU has reported to be effective, safe, and well tolerated option Hypoechoic areas were gradually decreased in size at follow-up
[53]	40 pts (20 PRP vs 20 CSI)	CNP	To evaluate the efficacy and imaging changes between PRP and CSI in the treatment of PFS	Pain, PF thickness, echogenicity, vascularity and function	NR	VAS, AOFAS, B-mode US, MRI	PRP vs CSI	NR	US was done at baseline, 3 and 6 ms MRI was done at baseline and 6 ms, VAS and AOFAS results was evaluated at baseline, 6 and 12 ms after treatment	The PF thickness has significantly decreased at 3-ms follow-up in both groups. The echogenicity and vascularity have significantly reduced at 3 and 6-ms follow-up in PRP group only. Thus, PRP injection is a safe and more efficient than CSI in treatment of PFS

Table 3 (Continued)

References	Sample size	Des	objective	Outcome measures	Position for assessment	Measurement tools	Type of intervention	Site of measurement	Follow-up	Conclusion
[54]	60 pts (30 PRP vs 30 CSI)	RCT	To evaluate the effectiveness of local injection of PRP and CSI in the treatment of chronic PFS	Pain, PF thickness and function	NR	B-mode US, VAS and AOFAS score	PRP vs CSI	NR	At baseline, 6 weeks, 3 ms and 6 ms follow-up after injection	Over the time, PRP local injection was an effective treatment in improving the pain levels, foot function and PF thickness compared to CSI
[55]	34 patients (17 ESWT vs 17 LLLT)	RCT	To compare the efficacy of ESWT and LLLT on PF thickness, heel pain, and foot functions in patients with PFS	Pain, foot function and PF thickness	Prone position with knees fully extended and ankles in a neutral position	B-mode US, VAS and FFI	ESWT vs LLLT	At the point where PF is inserted into medial calcaneal tubercle	At baseline, immediate after the treatment, and after 1 m	Both ESWT and LLLT have a clinical improvement such as reducing pain and improving foot functions as well as reducing PF thickness in patients with PFS
[56]	90 patients -30 ST - 31 CSI - 29 combined ST + CSI	RCT	To evaluate the effects of ST, local CSI, or combined ST and CSI on chronic PFS	Pain, foot function and PF thickness	Prone with 90º flexed, foot hanging on the edge of table in neutral position	B- mode US, VAS and FFI	ST, CSI and combined ST + CSI	nr	-VAS and FFI at baseline and 6 ms post therapy -US at baseline, 1,2,3, 6,12 ms post therapy	the combination of CSI and ST had a superior effect on pain, foot function and PF thickness at all time points in patients with PFS as compared with either CSI or ST treatment
[57]	30 pts (15 ozone injection) vs 15 CSI)	RCT	To determine the effects of ozone injection and CSI in the treatment of chronic PFS	Pain, activity and PF thickness	Prone position with their feet hanging over the edge of the table	VAS, B-mode and FAAM	Ozone (O2–O3) injection vs CSI	At insertion and 1 cm distal to its insertion into the medial calcaneal tubercle	At baseline, 2 and 12 weeks after injection	Ozone injection and CSI were effective in long term and short term, respectively. Both Ozone injection and CSI were observed to reduce pain and PF thickness and enhance foot function
[58]	64 pts (36 PRP injection vs 28 KT)	RCT	to compare the effectiveness of PRP vs KT with phonophoresis in the treatment of chronic PFS	Disability and activity and PF thickness	prone Position with ankle in a neutral position	NRS, FFI and B-mode US	PRP vs KT with phonophores-is	At calcaneal attachment	NRS at baseline, 2,6,12 and 24 weeks FFI and US at baseline, 6,12 and 24 weeks	PRP was better in relief pain in short time follow-up whereas it is better in improving NRS, functional status and PF thickness in long time follow-up compared to KT with phonophoresis

Table 3 (Continued)

References	Sample size	Des	objective	Outcome measures	Position for assessment	Measurement tools	Type of intervention	Site of measurement	Follow-up	Conclusion
[60]	110 pts (55 ESWT vs 55 CSI)	RCT	To assess efficacy of CSI and ESWT in PFS patients to determine the correlation between clinical outcomes and the PF thickness	Pain and PF thickness	NR	VAS, 100-points scoring systems and B-mode US	ESWT vs CSI	At insertion and 5 mm distal to calcaneus tuberosity	At baseline, 4 and 12 wk	The positive changes in PF after ESWT treatment is given better clinical outcomes in PFS patients
[61]	80 pts(40 PRP vs 40 CSI)	RCT	To evaluate the efficacy of local CSI vs PRP in the management of PFS	Pain, activity, foot function and PF thickness	NR	VAS, modified Roles and Maudsley score, FAI, AOFAS, B-mode US	PRP vs CSI	NR	At baseline at 1 m, 3 ms, and 6 ms after treatment	Both CSI or PRP was equally effective on clinical outcomes and PF thickness in patients with PFS
[62]	72 pts (36 rESWT vs 36 CSI)	RCT	To compare the clinical and sonographic effects of rESWT and CSI in patients with PFS	Pain, function and PF thickness and echogenicity	NR	VAS, FFI, HTI score and B-mode US	rESWT vs CSI	At the point where PF inserted into calcaneal tuberosity	At baseline and 1, 3, and 6 ms after treatment	rESWT noted to be superior to CSI in improving clinical outcomes and PF changes due to its long-term action
[63]	60 pts (40 ESWT vs 20 controls)	LF	To evaluate the efficacy of ESWT in the treatment of chronic PFS in patients with calcaneal spur using US	Pain, function and PF thickness	Prone with toes placed over the end of the examination table	VAS, Maudsley score, x-ray and B-mode US	ESWT	At 2 cm distal to the calcaneal insertion	At baseline and 8 weeks after treatment	PF has thickened in calcaneal spur patients. ESWT found to decrease the PF thickness and improve pain and function significantly
[64]	30 pts (15 PRP vs 15 dry needling)	RCT	To compare the treatment effects of PRP and dry needling on chronic PFS	Foot function, PF thickness, echogenicity and vascularity	NR	FFI, B-mode and power Doppler US	PRP vs dry needling of myofascial meridian trigger points	NR	At baseline, 6 and 12 weeks after treatment	A clinical and US improvement were observed in PRP group at 12-weeks follow-up in patients with chronic PFS

Table 4 Details of studies conducted on the evaluation of PF changes between patients with PFS and healthy subjects using US

References	Sample size	Des	Objective	Outcome measures	Position for assessment	Measurement tools	Type of intervention	Site of measurement	Follow-up	Conclusion
[37]	38 pts (19 PFS pts vs 21 healthy controls)	CC	To compare stiffness of PF between patients with PFS and healthy subjects using SWE and to correlate SWE values with clinical scores	PF thickness, SWV and stiffness, clinical scores	Prone position with foot hanging over the end of table	B-mode US, SWE, VAS, FFI	NA	1 cm distally from the calcaneal insertion	NA	SWE allows quantitative evaluation of the elasticity of the PF and can show PFS alterations. SWE shows a strong correlation with clinical scores
[39]	108 pts (87 pts and 21 healthy subjects)	CC	To evaluate the PF between healthy subjects and PFS patients by SWE with correlation to B-mode and CDUS and to establish cut-off values	PF thickness, vascularity grades, SWV and stiffness	NR	B-mode, color Doppler US and SWE	NA	Thickness was measured at calcaneus insertion. ROI was set within the thickest part of the PF. CDUS was applied on whole fascia	NA	SWE was able to quantitatively assess the PF stiffness, which reduces in patients with PFS. PF was thickened in PFS compared to healthy fascia No correlation of vascularity was found between both groups
[40]	82 pts (39 PFS, 23 unilateral healthy foot and 20 bilateral healthy feet)	CC	To determine the diagnostic potential of SWE and the correlation of clinical scores to SWE values	PF thickness, clinical scores, SWV and stiffness	Prone position with the foot hanging over the edge of table	B-mode, SWE, AOFAS and FFI	NA	At the calcaneus insertion; + 1 cm distal of the calcaneus and central part of the calcaneus	NA	SWE appears to enhance the diagnostic accuracy in patients with PFS as compared with B-mode US
[59]	40 subjects (20 PFS pts vs 20 controls)	CC	To determine the influence of MTP joint extension on PF thickness in healthy subjects compared to those unilateral PFS	PF thickness measured at rest, 30° of MTP joints extension and maximalpossible extension	Prone, the foot over the edge of the table and the ankle in neutral position	B-mode	NA	At the anterior margin of the calcaneus	NA	MTP joint position was effective in the measurement of PF thickness

Table 5 Matching control studies in evaluating the PF changes under different conditions using ultrasound

References	Sample size	Des	Objective	Outcome measures	Position for assessment	Measurement tools	Type of intervention	Site of measurement	Follow-up	Conclusion
[35]	22 pts (10 ESWT vs 12 sham-ESWT)	RCT	To investigate the efficacy and tolerability of ESWT in patients with PFS in axSpA	Pain, foot function, PF thickness and morphology	Prone with full knee extension and 90° dorsiflexion of the ankle	B-mode US, VAS, heel pressure algometry, FFI	ESWT vs sham-ESWT	At 5 mm distal to the calcaneal insertion from the medial aspect	At baseline, 1, 4, 8 weeks after the last therapy	ESWT was a safe and tolerable physical therapy to improve chronic heel pain due to PFS in patients with axSPA with no significant effect on PF
[37]	38 pts (19 PFS pts vs 21 healthy controls)	CC	To compare stiffness of PF between patients with PFS and healthy subjects using SWE and to correlate SWE values with clinical scores	PF thickness, SWV and stiffness, clinical scores	Prone position with foot hanging over the end of table	B-mode US, SWE, VAS, FFI	NA	1 cm distally from the calcaneal insertion	NA	SWE allows quantitative evaluation of the elasticity of the PF and can show PFS alterations. SWE shows a strong correlation with clinical scores
[39]	108 pts (87 pts and 21 healthy subjects)	CC	To evaluate the PF between healthy subjects and PFS patients by SWE with correlation to B-mode and CDUS and to establish cut-off values	PF thickness, vascularity grades, SWV and stiffness	NR	B-mode, color Doppler US and SWE	NA	Thickness was measured at calcaneus insertion. ROI was set within the thickest part of the PF. CDUS was applied on whole fascia	NA	SWE was able to quantitatively assess the PF stiffness, which reduces in patients with PFS. PF was thickened in PFS compared to healthy fascia No correlation of vascularity was found between both groups
[40]	82 pts (39 PFS, 23 unilateral healthy foot and 20 bilateral healthy feet)	CC	To determine the diagnostic potential of SWE and the correlation of clinical scores to SWE values	PF thickness, clinical scores, SWV and stiffness	Prone position with the foot hanging over the edge of table	B-mode, SWE, AOFAS and FFI	NA	At the calcaneus insertion; + 1 cm distal of the calcaneus and central part of the calcaneus	NA	SWE appears to enhance the diagnostic accuracy in patients with PFS as compared with B-mode US

Table 5 (Continued)

References	Sample size	Des	Objective	Outcome measures	Position for assessment	Measurement tools	Type of intervention	Site of measurement	Follow-up	Conclusion
[46]	60 pts (30 DP and 30 controls given saline)	RCT	To evaluate the therapeutic effects of DP in the treatment of PFS compared to control group	Pain, foot disability, PF thickness	Prone with the ankle placed in the neutral position	B-mode, VAS-A, VAS-R and FFI	DP vs control group (given saline)	NR	At baseline, at 7 and 15 weeks post-treatment	Improvement in PF thickness, foot function and pain was significantly higher in DP group than in control group
[48]	94 (44 pts and 50 healthy controls)	RCT	To determine the efficacy of high-resolution US in the evaluation of PF in patients with heel pain	PF thickness	Prone with foot hanging over the edge of the table with ankle in dorsiflexion	B-mode	NA	Within 1 cm from calcaneal attachment	NA	PFS can be easily diagnosed by US with PF > 4 mm in thickness
[50]	120 (60 EA, 30 SA, 30 controls)	RCT	To compare the efficacy of EA and SA versus waitlist control for improving the pain in patients with chronic PFS	Pain, disability, PF thickness	Prone position	B-mode, VAS, PPT, AROM and FAAM	EA vs SA vs non-treatment control	At the thickest portion closest to the calcaneal insertion in its medial tuberosity	At baseline, 4 weeks, with a 12-weeks follow-up	Assessment of PF thickness may detect the anatomical changes that occur in the PF after acupuncture
[59]	40 subjects (20 PFS pts vs 20 controls)	CC	to determine the influence of MTP joint extension on PF thickness in healthy subjects compared to those unilateral PFS	PF thickness measured at rest, 30° of MTP joints extension and maximal possible extension	Prone with the examined foot over the edge of table and the ankle in neutral position	B-mode	NA	At the anterior margin of the calcaneus	NA	MTP joint position was effective in the measurement of PF thickness
[63]	60 pts (40 ESWT vs 20 controls)	LF	To evaluate the efficacy of ESWT in the treatment of chronic PFS in patients with calcaneal spur using US	Pain, function and PF thickness	Prone with toes placed over the end of the examination table	VAS, Maudsley score, x-ray and B-mode US	ESWT	At 2 cm distal to the calcaneal insertion	At baseline and 8 weeks after treatment	PF has thickened in calcaneal spur patients. ESWT found to decrease the PF thickness and improve pain and function significantly

Two studies conducted by Schillizzi et al. [37] and Gatz et al. [40] compared the PF thickness and stiffness features between patients with PFS and healthy subjects and correlated the SWE values with clinical scores. The studies showed that SWE can be quantitatively assessed the stiffness of PF and can diagnose PFS changes. SWE was strongly correlated with clinical scores. The SWE measured the PF stiffness and SWV and B-mode measured the PF thickness can improve the diagnostic accuracy of ultrasound in diagnosis the PFS.

Granado et al. [59] investigated and compared the effectiveness of metatarsal phalangeal (MTP) joints extension on PF thickness in 40 subjects divided into two groups (20 unilateral PFS and 20 healthy subjects). The PF thickness was evaluated at rest, 30 degrees of extension from the plantar aspect, and maximal extension as much as possible. The study found that PF thickness reduced significantly with MTP joints extension in both PFS and healthy groups. Therefore, the study concluded that PF thickness could be influenced by MTP joints extension. Thus, the researchers recommended that PF thickness should be measured with toes at rest.

Comparing the PF changes between study group and matching control

As outlined in Table 5, 9 studies with different designs [35, 37, 39, 40, 46, 48, 50, 59, 63] evaluated PF changes in patients with PFS and control groups with or without interventions. Two randomized controlled trials [35, 46] conducted to evaluate the PF changes in patients with PFS underwent different interventions for different intervals. The PFS patients were divided into two groups: treatment group and placebo group. Caner et al. [35] observed no changes in PF thickness pre and post intervention in treatment group and placebo group. However, Mansiz-Kaplan et al. [46] stated that PF was significantly thicker in treatment group than in placebo group. Four case–control studies [37, 39, 40, 59] evaluated the PF thickness and its observation changes in patients with PFS and healthy subjects with no interventions using different ultrasound modes. Three more experimental studies [48, 50, 63] investigated PF thickness alone using ultrasound in patients with PFS received a treatment and healthy volunteers. In the latter three studies, PF thickness increased in patients with PFS as well as responded to the treatment as compared to healthy subjects.

Conclusion

This study was designed to systematically review published articles from 2017 to 2022 regarding the application of the ultrasound in evaluating the PF changes in patients with PFS. When the published articles have been reviewed, many differences were noted in methodology, sample size, study design, intervention and duration of follow-up. The findings revealed that ultrasound is reliable, accurate, safe, and non-invasive imaging tool in the assessment of PF changes, therapeutic guiding and observing different treatments in patients with PFS. The most suitable site to evaluate the PFS is at the point where PF is inserted into medial calcaneal tubercle and 1 cm distal to its insertion. The longitudinal scan is considered as the best scan for imaging the PF in which the probe is placed on the line between medial tuberosity of the calcaneus and the second finger over the PF. The thickness, echogenicity, vascularization and stiffness of the PF are the most sonographic outcome measures used in the evaluation of the PFS using B-mode, color doppler and SWE (Figs. 2, 3, 4, 5 and 6).

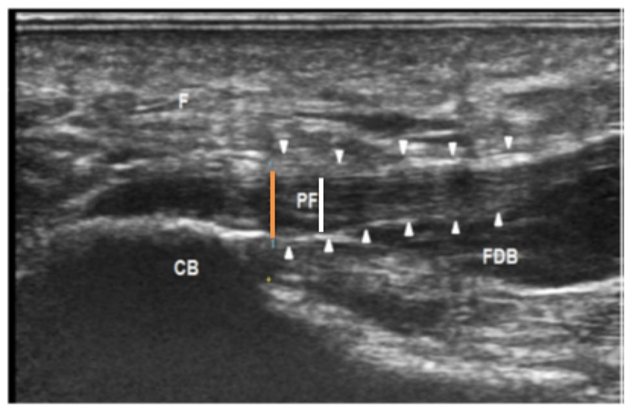


Fig. 2 A longitudinal sonographic scan of a patient with PFS, showing the measurement of the PF thickness (arrowhead) at calcaneal insertion (orange line) and 1 cm distal to the insertion (white line). *CB* calcaneus bone, *F* fat pad, *FDB* flexor digitorum brevis muscle, *PF* plantar fascia (adopted from Ref. [36])

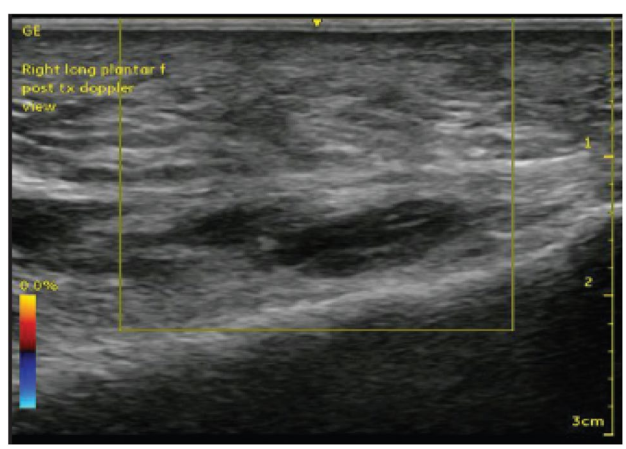


Fig. 3 Color Doppler ultrasound images of the PF, showing no neovascularization in PF (adopted from Ref. [65])

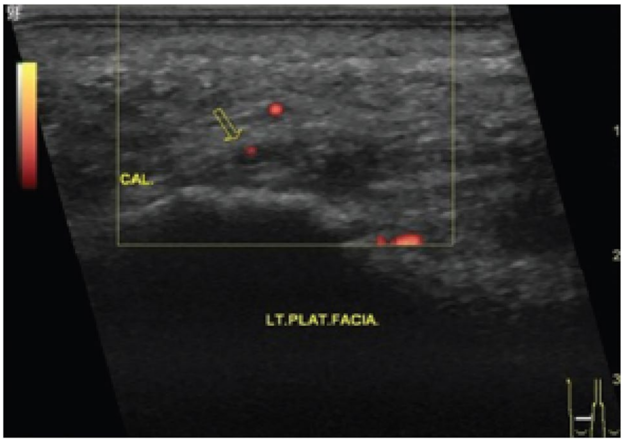


Fig. 4 Power Doppler ultrasound of PF showing one single vessel (adopted from Ref. [64])

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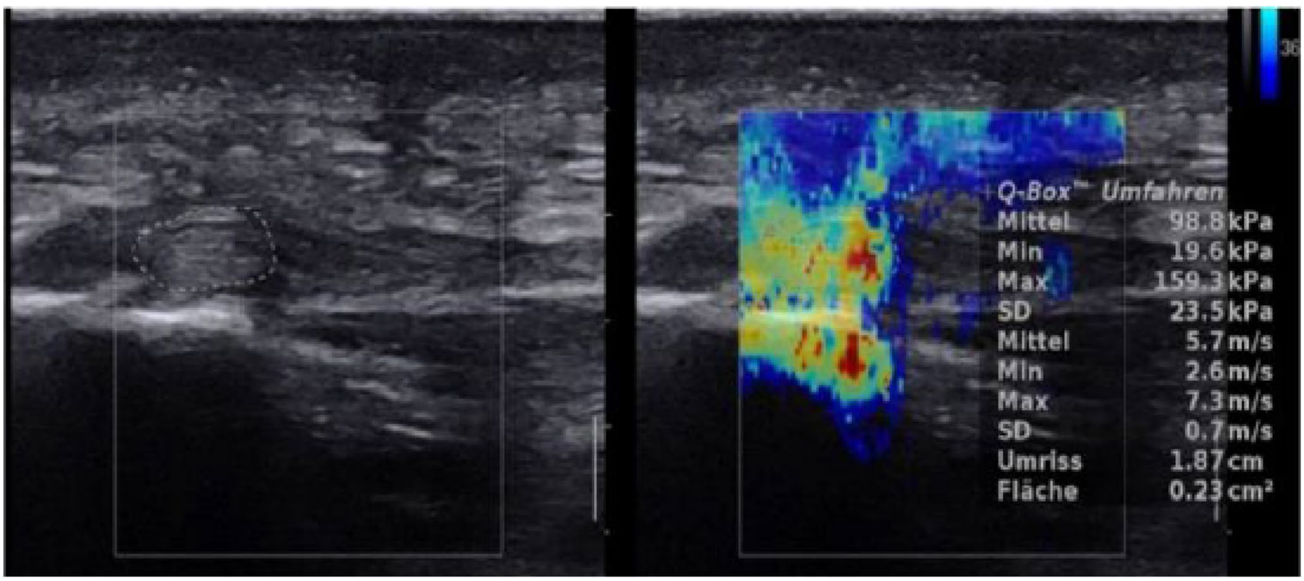

Fig. 5 A longitudinal SWE and B-mode ultrasound images of normal PF shows stiffness of 98.8 kPa and SWV value of 5.7 m/s (adopted from Ref. [39])

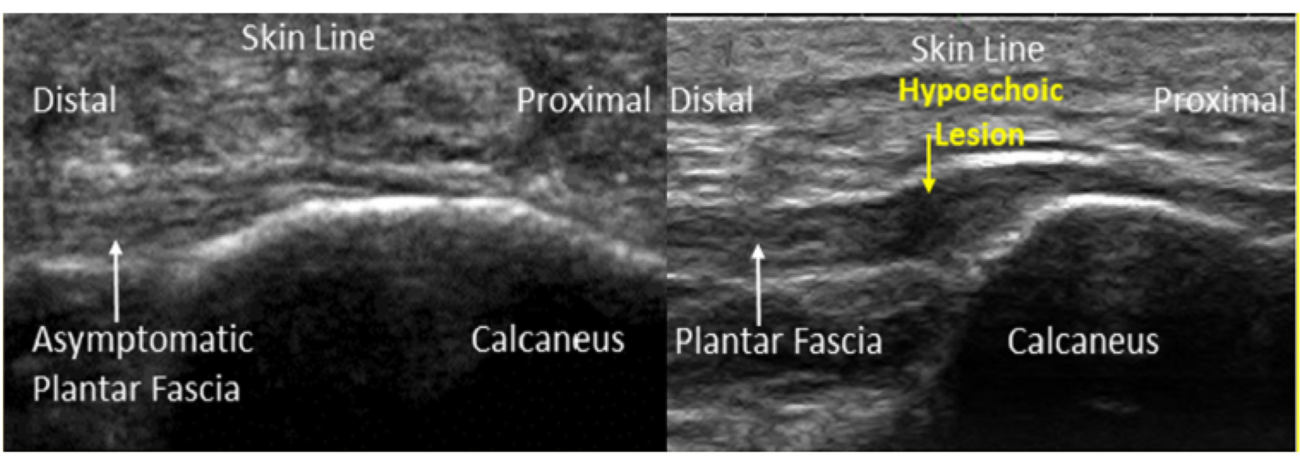

Fig. 6 A longitudinal ultrasound images of PF. Normal appearance of asymptomatic plantar fascia (left) and chronic PFS with hypoechoic lesion (right) (adopted from Ref. [52])

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Declarations

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Human rights and informed consent This review does not include any study with human subjects conducted by any of the authors.

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