Original Contribution

Short title: Sonoelastography of plantar fascia

Sonoelastography of Plantar Fascia: Reproducibility and Pattern Description in Healthy Subjects and Symptomatic Subjects

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Abstract

The purpose of the work reported here was to describe the sonoelastographic appearance of the plantar fascia of healthy volunteers and patients with fasciitis. Twenty-three healthy subjects and 21 patients with plantar fasciitis were examined using B-mode and real-time sonoelastography (RTSR) scanning. B-Mode examination included fascia thickness and echotexture. Echogenicity and echovariation of the color histogram were analyzed. Fasciae were classified into type 1, blue (more elastic); type 2, blue/green (intermediate); or type 3, green (less elastic). RTSE revealed 72.7% of fasciae as type 2, with no significant association with fasciitis ($\chi^2 = 3.6$, $df = 2$, $p = 0.17$). Quantitative analysis of the color histogram revealed a significantly greater intensity of green (mean = 77.8, 95% confidence interval [CI] = 71.9–83.6) and blue (mean = 74.2, 95% CI = 69.7–78.8) in healthy subjects. Echovariation of the color red was 33.4% higher in the fasciitis group than in the healthy group (95% CI = 16.7–50.1). Sonoelastography with quantitative analysis of echovariation can be a useful tool for evaluation of plantar fascia pathology.

Key Words: Elasticity imaging techniques; Ultrasonography; Plantar fasciitis; Comparative study; Adults

Introduction

Plantar fasciitis is a degenerative syndrome of the plantar fascia and is reported to be the most common cause of inferior heel pain in adults (Rompe 2009; Wearing et al. 2006). Ultrasonography is a useful tool for the assessment of fascia pathology because it allows clinical diagnosis and confirms the exact location of the fasciopathy (Ieong et al. 2013; McMillan et al. 2009).

Real-time sonoelastography (RTSE) is a new ultrasound-based imaging technique that provides information on tissue elasticity and stiffness (Turan et al. 2013). The principle underlying elastography is that tissue compression produces a strain (displacement) within the tissue, providing a color-coded image superimposed over the B-mode image. The color indicates the relative elasticity of tissues within the region of interest (ROI) (Wu et al. 2011).

Real-time sonoelastography has been applied to the musculoskeletal system to evaluate lateral epicondylitis (De Zordo et al. 2009b), to describe the elasticity pattern of normal (De Zordo et al 2009a; Drakonaki et al. 2009) and damaged (Sconfienza et al. 2010; Tan et al. 2012; Turan et al. 2013) Achilles tendon, and a number of articles on RTSE of plantar fascia have also been published. Wu et al. (2011, 2012) reported plantar fascia softening in subjects with the characteristic symptoms of plantar fasciitis and propose a quantitative measurement of the color histogram. This quantitative method allows a more objective interpretation than color visual grading, although postexamination analysis is required (Sconfienza et al. 2011). The loss of elasticity of affected plantar fascia has been reported to precede morphologic changes visible on B-mode imaging using semiquantitative methods (Lee et al. 2014; Sconfienza et al. 2013).

The disadvantages of RTSE include operator dependency and reproducibility (Havre et al 2008). Previous studies have assessed inter-observer agreement on visual inspection of elastograms (Lee et al. 2014; Sconfienza et al. 2013; Wu et al. 2011). However, to the best of our knowledge, the reliability of RTSE image acquisition has not been addressed to date.

The purpose of this study was to describe the sonoelastographic appearance of the plantar fascia of healthy volunteers and patients with symptomatic plantar fasciae and to evaluate RTSE reproducibility in image acquisition. We also performed correlation analyses of RTSE findings with subjective heel pain, perceptions of health status and ultrasound findings.

Methods

Study population

The institutional review board approved the study, and informed written consent was obtained from all volunteers and patients. A total sample size of 34 subjects was calculated for $\alpha = 0.05$, $\beta = 0.20$, and a minimum effect size of 0.5 for quantitative variables. Because a 15% loss in cases was estimated, we recruited 23 volunteers older than 18 years with no history of fascia disorders or painful episodes and 15 patients with plantar fasciitis. Inclusion criteria were (i) heel pain at the proximal fascia insertion, (ii) worse pain when waking up in the morning or after a period of rest and (iii) a visual analog scale (VAS) score >4 on a scale of 10. Patients who had undergone surgery or steroid injections to the heel were excluded. The Spanish version of the SF-36 Health Survey, Version 2, was administered to all patients (Alonso et al. 1995).

Imaging

The examination included B-mode scanning and RTSE using a US scanner (LogiqS8 of General Electric) with a 6- to 15-MHz linear array transducer (ML6-15). All examinations were conducted by a sonographer (~~J.R.D.~~J.J.M.P.) with more than 10 years' experience in musculoskeletal imaging. Each subject was examined while lying prone with 90° of knee flexion in the neutral ankle position (Pascual Huerta and Alarcón Garcia 2007; Wu et al. 2011). The fascia was first assessed by B-mode ultrasound for thickness and echotexture. In a longitudinal view, the thickness of the plantar fascia was measured from the anterior edge of the inferior calcaneal border vertically to the inferior border of the plantar fascia (Kane et al. 2001; Wu et al. 2011). All system setting parameters, such as gain (50 dB), time gain compensation (in neutral position), depth (2.8 cm), frequency (9 MHz), compression (D/O) and focus (two focal points at 1.1 and 1.8 cm) were constant throughout the study.

Real-time sonoelastography records were acquired in the same position by applying gentle compression with the transducer using a freehand technique. The pressure was adjusted according to the visual indicator for compression on the video screen, and a quality factor ≥60 indicated the optimal compression force (Wu et al. 2011). RTSE records were converted to AVI files with a resolution of 960 × 540 pixels for off-line analysis. Three images of every video were stored uncompressed and with no losses in bitmap format (bmp), and the mean value of histogram components was used for statistical analysis.

A subgroup of 15 subjects were explored again by the original sonographer (~~J.R.D.~~J.J.M.P.) and another (~~J.J.M.P.~~A.d.G.F.) who was blinded to the previous results to analyze intra- and inter-sonographer reliability in imaging acquisition. The two sonographers were researchers with more than 10 years of experience performing musculoskeletal ultrasound examinations. Both operators had musculoskeletal disorders as their specialty and examined several patients each day using US. As physical activity and time of day might influence the actual thickness of the plantar fascia (Grigg et al. 2010; Skou et al. 2012), we chose to use a period about 30 min between test and retest, and all participants remained seated between sessions.

Imaging analysis

Two research scientists (M.E.d.B.A. and ~~A.d.G.F.~~J.R.D.) with training in musculoskeletal ultrasonography reviewed the images for qualitative and quantitative imaging analysis. These two researchers, who were unaware of the clinical status, visually inspected the whole proximal section of the fascia included in the standardized window and graded in consensus the quality of echotexture according to Archambault et al. (1998): grade 1 = normal appearance (parallel margins, homogeneous echotexture); grade 2 = enlarged structure (bowed margins, homogeneous echotexture); grade 3 = hypo-echoic area with or without enlargement. They also classified fasciae into three main types on the basis of elasticity features (De Zordo et al 2009a; Tan et al. 2012): type 1 = blue (more elastic tissue); type 2 = blue/green (intermediate tissue); type 3 = green (less elastic tissue). In addition, three subtypes were determined: (i) homogeneous, (ii) relatively homogeneous and (iii) heterogeneous. For homogeneous fasciae, no red color is evident, relatively homogeneous fasciae have small red stripes and heterogeneous fasciae exhibit scattered fields in the form of patches over a dominant pattern (Tan et al. 2012).

We used ImageJ 1.46a software (W. Rasband, National Institutes of Health, USA, 2013) to perform quantitative analysis of gray-scale images and the color histogram of the elastogram. The color histogram computed the mean and dispersion intensity of red, green and blue channels (color intensity range: 0–255) within an area (Wu et al. 2011). For this quantitative analysis, we selected the part of the fascia visible on the RTSE screen by manually delineating the outer margin of the fascia, excluding the surrounding tissues (Fig. 1). Two research scientists (M.E.d.B.A. and ~~A.d.G.F.~~J.R.D.) performed the manual ROI drawing of all the images twice, 1 week apart, to evaluate intra- and inter-observer reliability. The mean echogenicity of each ROI was calculated with ImageJ software.

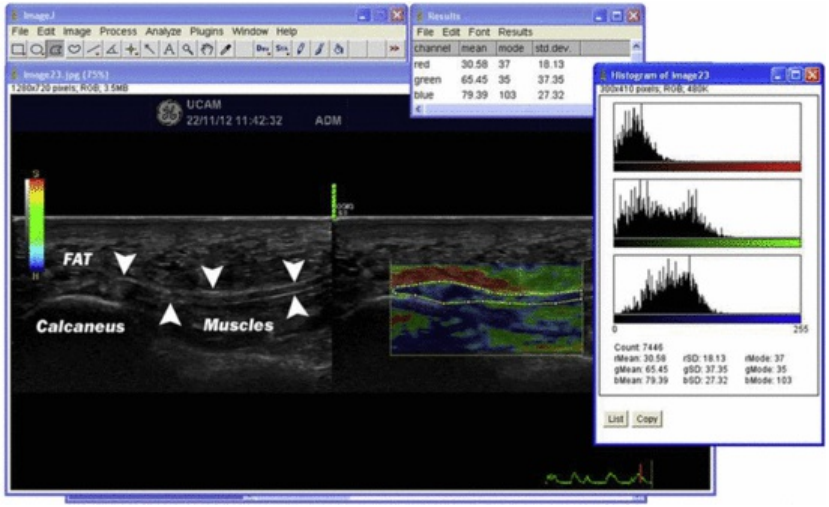

Fig. 1 Twenty-six-year-old man from control group. Longitudinal B-mode ultrasound image (left), revealing normal plantar fascia (*arrowheads*). Quantitative analysis real-time sonoelastography (right) with color histogram (*red*, *green* and *blue channels*).

Echovariation (EV) was determined by the relation between standard deviation and mean pixel intensity. EV is a texture parameter that can be interpreted as the uniformity of the ultrasonographic pattern (Gdynia et al. 2009; Ríos-Díaz et al. 2010),

$$\mathrm{EV} = \frac{\sqrt{\sum_{i=0}^{n-1}(i-\mu)^2 p_i}}{\sum_{i=0}^{n-1} i p_i} \cdot 100 \quad (1)$$

where i is pixel intensity, n is intensity color level, p_i is pixel intensity probability and μ is mean pixel intensity.

Statistical analysis

Collected data were analyzed with the SPSS Statistics, Version 19.0 (IBM, Armonk, NY, USA). Standard descriptive statistics were used to summarize characteristics of the sample and categorical variables. The χ^2-test and odds ratios (ORs) were used to test differences between qualitative descriptions of the elastogram. The normality of the distribution (Shapiro–Wilks test) and the homoscedasticity of the quantitative variables (Levene's test) were determined.

One-way analysis of covariance (corrected for age and body mass index because baseline mean differed between the groups) was used to test quantitative variables (thickness, echogenicity and echovariation), and the size effect was determined with Cohen's *d*.

Intraclass correlation coefficients (ICCs) for a two-way mixed effect model and absolute agreement were calculated to determine inter- and intra-sonographer and inter- and intra-observer reliability of echogenicity and fascia thickness. Each researcher's first measure was used to determine inter-observer reliability to control learning effect. In addition, the agreement interval (95% AI) was assessed using the Bland and Altman's scatterplot method, and the Passing–Bablok regression was used to determine constants or proportional bias. The quadratic-weighted κ coefficient and agreement frequencies were used for reliability of categorical variables. Next, criteria were used to judge the reliability coefficients: very low (<0.20), low (0.21–0.40), moderate (0.41–0.60), good (0.61–0.80) and very good (0.81–1.00) (Landis and Koch 1977).

Correlations between parameters were analyzed with Spearman's non-parametric correlation or with Pearson's parametric correlation for ultrasound, RTSE and clinical findings. A p value < 0.05 was accepted as statistically significant.

Results

Twenty-three healthy subjects (M/F ratio = 12/11, mean age = 23.7 y, SD = 3.18 y) and 21 patients with plantar fasciitis (M/F ratio = 18/3, mean age = 38.0 y, SD = 8.64 y) were included in the study. The fasciitis group was significantly older and had a higher weight and higher body mass index than the healthy subjects (Table 1). Although the weekly time dedicated to physical activity was slightly higher for the fasciitis group, the difference was not statistically significant. For this reason all analyses with quantitative variables were corrected for age and body mass index.

Table 1 Sociodemographic characteristics of healthy subjects and fasciitis patients*

Variable	Fasciitis (n = 21)		Healthy (n = 23)		*p* value†
	Mean (SD)	95% CI	Mean (SD)	95% CI	
Age (y)	38.0 (8.64)	34.1–42.0	23.7 (3.18)	22.8–24.7	<0.001
Weight (kg)	82.1 (12.73)	76.3–88.1	68.5 (13.21)	64.6–72.5	<0.001
Height (m)	1.76 (0.081)	1.72–1.79	1.71 (0.095)	1.68–1.74	0.084
Body mass index (kg/m^2)	26.5 (3.00)	25.2–27.9	23.3 (2.62)	22.5–24.0	<0.001
Physical activity (h/wk)	5.2 (3.36)	3.5–6.7	3.7 (3.03)	2.8–4.6	0.169
Visual analog scale score	5.2 (1.91)	4.4–6.1	–	–	–
Evolution (months)	15.4 (9.44)	11.1–19.7	–	–	–
SPCS (SF-36)	47.2 (5.79)	44.5–49.8	–	–	–
SECS (SF-36)	50.2 (5.26)	47.8–52.6	–	–	–

95% CI = 95% confidence interval; SPCS = Standardized Physical Component Scale; SECS = Standardized Emotional Component Scale.

* Standardizations were calculated over a Spanish reference population with a *t*-score (Alonso et al. 1995).

† Student's *t*-test for independent samples.

Both mean VAS score (5.2 patients, 95% confidence interval [CI]: 4.4–6.1 patients) and mean evolution time (15.4 mo, 95% CI: 11.1–19.7 mo) exhibited great variability in the fasciitis group. The scores for the physical and emotional components obtained from the perceived quality of life SF-36 questionnaire were similar to those of the reference healthy population.

Ultrasound

A total of 23 plantar fasciae from healthy volunteers and 21 plantar fasciae from patients with plantar fasciitis were analyzed. The mean plantar fascia thickness of the healthy group, 3.2 mm (SD: 0.70 mm, range: 2.93–3.51 mm), was significantly smaller than that of the fasciitis group (3.9 mm, SD: 1.47 mm, range: 3.0–4.4 mm). On average, affected fasciae were 0.7 mm thicker than healthy fasciae (95% CI: ~~1.0–1.41~~0.3-1.0 mm, $p = 0.041$) with a large effect size. Inter-sonographer reliability was found to have an ICC of 0.524 with a mean difference of –0.003 (95% AI: –0.18, 0.17), whereas intra-sonographer reliability was higher, with an ICC of 0.672 and a mean difference of 0.044 (95% AI: –0.22, 0.30).

In 20 (87%) of the 23 healthy fasciae, grade 1 was present, whereas alterations of grade 3 were found in 14 symptomatic plantar fasciae (66.7%) (Table 2). The Chi-square test was statistically significant ($\chi^2 = 27.2$; df = 2; $p < 0.001$). Therefore, there is an association between quality echotexture and fasciitis; quality echotexture predicts moderate fasciitis (OR = 5.34, 95% CI: 2.59–11.03). Reliability testing with κ statistics revealed that the degree of agreement was good for intra-sonographer measurements (κ = 0.75, 95% CI: 0.57–0.93, $p < 0.01$), with 88.9% agreement, and also for inter-sonographer agreement (κ = 0.78, 95% CI: 0.36–1.0, $p < 0.01$), with 99% agreement.

Table 2 RTSE and B-mode ultrasound findings in the healthy and fasciitis groups

Variable	Fasciitis group (n = 21)	Healthy group (n = 23)	Total (n = 44)	Odds ratio (95% CI) *p* value*
Elasticity RTSE				
Type 1	2 (9.5)†	6 (26.1)	8 (18.2)	1.45 (0.542–3.89) $p = 0.169$
Type 2	18 (85.7)	14 (60.0)	32 (72.7)	
Type 3	1 (4.8)	3 (13.1)	4 (9.1)	
Homogeneity RTSE				
Subtype 1	19 (90.5)	20 (87.0)	39 (86.6)	0.863 (0.153–4.86) $p = 0.867$

Subtype 2	2 (9.5)	3 (13.0)	5 (11.4)	
Subtype 3	–	–	–	
Echotexture US				
Grade 1	5 (23.8)	20 (87.0)	25 (56.8)	5.34 (2.59–11.03) $p < 0.001$
Grade 2	2 (9.5)	1 (4.3)	3 (6.8)	
Grade 3	14 (66.7)	2 (8.7)	16 (36.4)	

95% CI = 95% confidence interval; n = number of fasciae; RTSE = real-time sonoelastography; US = B-mode ultrasonography.

* Chi-square test. ORs were calculated logistic regression.

† Number (%).

The quantitative analysis of the gray level (echogenicity) obtained with US B-mode revealed that the respective mean values for the healthy and fasciitis groups were 66.1 (SD = 9.27) and 56.3 (SD = 13.48). Echogenicity was significantly 9.8 gray levels lower in the fasciitis group than in the healthy group (95% CI: 2.8–16.8, $p = 0.007$), with a large size effect. However, the echovariation was 5.7 units higher (95% CI: 2.0–9.3, $p = 0.003$) in the fasciitis group that in the healthy group, and the size effect was also large (Table 3). With respect to the reliability of quantitative analysis of gray level, the inter-sonographer ICC was 0.788, with a mean difference of –6.4 (95% AI: –20.0, 7.2), and the intra-sonographer ICC was 0.891, with a mean difference of –0.55 (95% AI: –14.1, 15.2).

Table 3 Quantitative RTSE and B-mode ultrasound in the healthy and fasciitis groups

Variable	Channel	Fasciitis (n = 21)		Healthy (n = 23)		*p* value*	Size effect†
		Mean (SD)	95% CI	Mean (SD)	95% CI		
Thickness (mm)		3.9 (1.47)	3.0–4.4	3.2 (0.70)	2.93–3.51	0.041	1.03
Echogenicity (0–255)	Gray	56.3 (13.48)	50.2–62.4	66.1 (9.27)	62.2–69.9	0.007	1.06
	Red	42.2 (16.56)	34.7–49.7	46.5 (10.30)	42.2–50.8	0.301	0.412
	Green	64.8 (13.98)	58.4–71.2	77.8 (13.98)	71.9–83.6	0.004	0.93
	Blue	62.1 (13.85)	55.8–68.4	74.2 (10.87)	69.7–78.8	0.003	1.12
Echovariation (%)	Gray	34.5 (6.07)	31.7–37.2	28.8 (5.87)	26.4–31.3	0.003	0.96
	Red	93.7 (35.86)	77.3–110.0	59.4 (10.21)	55.1–63.6	<0.001	3.36
	Green	54.6 (11.36)	49.4–59.8	44.1 (11.24)	39.4–48.8	0.004	0.94
	Blue	47.1 (13.39)	41.0–53.2	40.3 (8.83)	36.6–44.0	0.044	0.81

95% CI = 95% confidence interval; n = number of fasciae.

* One-way analysis of covariance corrected by age and body mass index.

† Size effect by Cohen's *d*.

Real-time sonoelastography

Real-time sonoelastography revealed most fasciae to be type 2 (32 fasciae, 72.7%) corresponding to blue/green fasciae and a medium elastic tissue. In the fasciitis group, 18 fasciae (85.7%) were found to be type 2. There was no statistically significant association between these findings and the presence of fasciitis ($\chi^2 = 3.6$, $df = 2$, $p = 0.17$) with an OR of 1.45 (95% CI: 0.542–3.89) (Table 2).

A total of 20 healthy fasciae (87%) and 19 symptomatic fasciae (90.5%) were classified with the visual typing system as subtype 1 (homogeneous structure), whereas the remainder (5/44 fasciae, 11.4% of the total) exhibited a relatively homogeneous

pattern. Subtype 3 (heterogeneous structure) was not found in any healthy volunteer or patient. There was no statistically significant association between the homogeneity findings and fasciitis ($\chi^2 = 0.03$, $df = 2$, $p = 0.867$) with an OR of 0.86 (95% CI: 0.153–4.86).

Exact agreement between the two sonographers was obtained in 70.8% of the examinations with respect to fascia elasticity and in 94.8% with respect to homogeneity, although the corresponding κ values were very low, 0.026 and 0.39, respectively. Intra-sonographer reliability was also characterized by κ statistics, which pointed to poor agreement for elasticity and homogeneity (κ = 0.08 and 0.15, respectively). However, the proportion of intra-sonographer agreement was 94.2% for elasticity typing and 92.2% for homogeneity classification.

With respect to quantification of RTSE, the RGB (red, green, blue) color images were split, and their respective histograms were analyzed separately (Fig. 2). The intra-rater reliability ICCs of M.E.d.B.A. and ~~A.d.G.F.~~J.R.D. for manual ROI drawing were 0.91 (95% CI: 0.80–0.96) and 0.82 (95% CI: 0.61–0.92), respectively. Inter-observer measures also revealed good reliability (ICC = 0.81, 95% CI: 0.72–0.92).

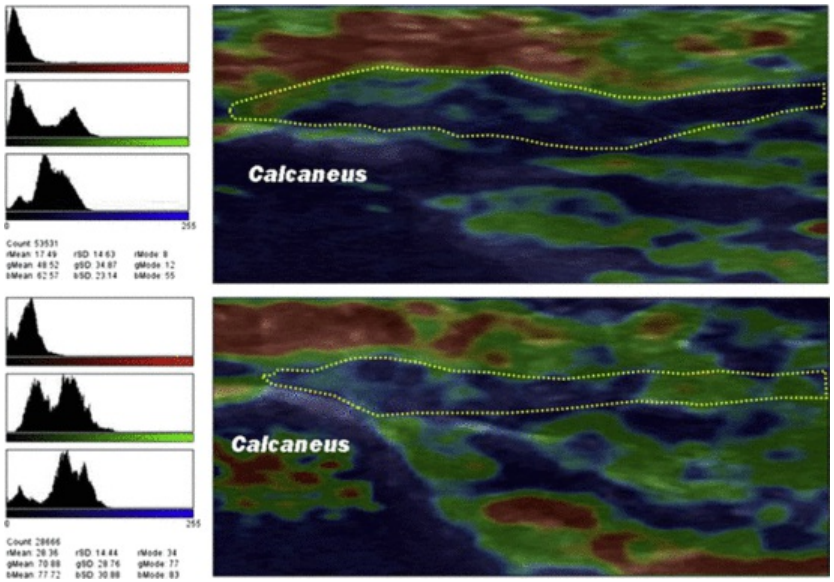

Fig. 2 Color histogram measurement of the plantar fascia included within the standardized area of the ultrasound elastogram. Top: Plantar fasciitis in a 40-year-old man with right heel pain and 10-mo history of tenderness at the medial aspect of the calcaneus. Bottom: Male patient (26 years old) from the control group. The patient with fasciitis had greater thickness, lower mean echogenicity and higher echovariation of color channels of the plantar fascia.

Quantitative analysis of the color histogram revealed that the respective mean values for red, green and blue intensity on the elastogram were 46.5 (SD = 10.30), 77.8 (SD = 13.98) and 74.2 (SD = 10.87) for healthy subjects and 42.2 (SD = 16.56), 64.8 (SD = 13.98) and 62.1 (SD = 13.85) for the fasciitis group. There was a significantly greater (about 12 levels of color) intensity of green ($p = 0.004$) and blue ($p = 0.003$) colors in healthy fasciae than in pathologic fasciae. There were statistical differences in echovariation for all colors; the fasciitis group exhibited higher heterogeneity than the healthy group (Fig. 3). Although the difference in the intensity of red between groups was not statistically significant, the red pattern was 34.3 points more variable in the fasciitis group than in the healthy group (95% CI: 18.5–90.0, $p < 0.001$), with a very high size effect (Table 3).

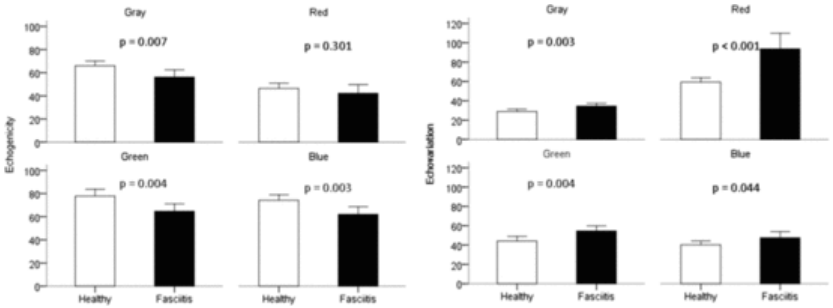

Fig. 3 Quantitative real-time sonoelastography and B-mode ultrasound parameters. *Bars* represent mean values and 95% confidence intervals.

Because some qualitative categories exhibited low frequencies, these variables were split into two categories for the χ^2-test. In the fasciitis group, there was a moderate degree of correlation between homogeneity and elasticity (Spearman's $\rho = 0.363$, $p = 0.001$). Fascia thickness was inversely and moderately correlated with echogenicity ($r = -0.33$, $p < 0.001$) and directly and moderately correlated with echovariation ($r = 0.36$, $p < 0.001$). However, there were no associations between the RTSE and US B-mode color grades in any group. No correlation was observed between RTSE color grades and clinical parameters (pain and quality of life) or between qualitative US B-mode findings and clinical parameters. Only a logical inverse correlation was found between VAS score and the emotional component of SF-36 ($\rho = 0.63$, $p = 0.002$).

Discussion

The current results indicate that the fasciitis group had a thicker fascia, with lower echogenicity and higher echovariation. Consistent with our research, findings that support the diagnosis of plantar fasciitis include a proximal plantar fascia thickness >4 mm and areas of hypo-echogenicity (Karabay et al. 2007; McMillan et al. 2009). Our values for fascia thickness are slightly lower; probably because the mean body mass index of our fasciitis group was lower than in previous studies, reflecting the association between this condition and obesity (Hill and Cutting 1989).

Although the intra-rater reliability of measuring plantar fascia thickness by ultrasonography has been reported to be very good (Karabay et al. 2007), the reliability of image acquisition has not been examined in detail. In a previous study, we evaluated the reproducibility of ultrasonography in Achilles tendon and the patellar ligament, with high reliability for both intra- and inter-rater evaluations in the case of tendon thickness (del Baño-Aledo et al. 2008; Sim and Wright 2005). In the present study, US inter-sonographer reliability of the plantar fascia revealed only a moderate ICC. Compared with the Achilles tendon or patellar ligament, the plantar fascia is a deeper structure, so its visualization is probably more influenced by sonographic attenuation of the overlying soft tissue, including the hyperkeratotic skin and heel fat.

Real-time sonoelastography qualitative classification revealed that there was no difference in the stiffness of the plantar fascia between groups. κ statistics indicated poor inter- and intra-sonographer agreement on the RTSE classification of elasticity and homogeneity, with a frequency of observer agreement <5 in several categories possibly contributing to this result. Because the magnitude of κ is affected by the frequency of observed agreement or disagreement, κ on its own is difficult to interpret meaningfully unless the proportion of agreement is taken into account (De Zordo et al. 2009b). In our research, the proportion of agreement was high between sonographers and within a sonographer, so the reliability of RTSE qualitative classification is not as bad as the κ values suggest.

With quantitative analysis, although the intensity of red did not differ between groups, the intensity of green and blue components was significantly lower in the fasciitis group, which reflects a less elastic fascia in patients. Despite differences in ROIs, these findings are consistent with Wu et al, (2011), although they used an inverted lookup table, where red color represented less elastic tissue, and blue, more elastic tissue. Like us, they do not find significant differences in the intensity of less elastic components between the fasciitis and healthy groups.

Loss of elasticity of the plantar fascia has been observed by other authors using semiquantitative methods. Lee et al. (2014) found a significantly higher proportion of patients with softening of plantar fascia than with healthy fascia (91% and 50%, respectively). These authors assessed plantar fascia as “hard” (blue area constituting more than 50% of the fascia) and “soft” (blue area constituting less than 50% of the fascia). Like Sconfienza et al. (2013), we prefer using the terms *more elastic* and *less elastic* rather than *soft* and *hard* to describe RTSE findings. They created a total elasticity score and found that patients with plantar fasciitis had higher median elasticity score compared with control subjects (median elasticity score = 11 and 6, respectively), which reflects less elastic fasciae in the first group.

To our knowledge, we are the first to analyzed echovariation in RTSE images. Echovariation of the three histogram components was significantly greater in the fasciitis group, which reflects changes in the structural echo pattern of the damaged fascia caused by advanced collagen degeneration with fiber disorientation, increased mucoid ground substance and angiofibroblastic hyperplasia (Rompe 2009; Wearing et al. 2006). Echovariation could provide more information on the structural characteristics of the tissue than echogenicity, which provides only the average intensity. Although this quantitative analysis performed with the public domain image processing program ImageJ is more time consuming than simple visual inspection, the analysis procedure is short and easy to carry out, and it allows a more objective measurement of elastographic data. In addition, an advantage of image analysis with ImageJ over conventional qualitative classification of RTSE images is its reproducibility and accuracy. This is an important advantage in the field of research, allowing us to deepen our understanding of plantar fascia injury. Although it is true that its application in everyday clinical practice may be difficult, future research should be conducted to incorporate these image analysis tools into ultrasound devices. An additional strength of our study is inclusion of the whole proximal section of fascia in the standardized window for qualitative analysis. This is clinically important because more than one-third of fasciitis occurs in the distal fascia (Ieong et al. 2013), so RTSE evaluation should include as much of the fascia as possible.

This study has a number of limitations. First, although we estimated the size sample with an α error of 5% and β error of 20%, our study sample was relatively small. Thus, further studies using larger populations are needed to verify these findings and to obtain more precise intervals. On the other hand, our sample sizes are similar to those encountered in previous RTSE studies that have generally been accepted by the relevant scientific community (Chino et al. 2012; De Zordo et al. 2009a; Ríos-Díaz et al. 2010; Tan et al. 2012; Wu et al. 2011). Second, no association between our ultrasound measurements and symptom severity was found. This lack of association could be due to the fact that pain and disability levels were, on average, quite low in our fasciitis group, which could have interfered with our ability to detect a correlation. The subjects with fasciitis who volunteered for our study were generally active people who managed to live busy lives despite the presence of pain. Third, in terms of the application of pressure to the probe, RTSE has a relatively high operator dependency (Havre et al 2008). To reduce biases caused by such a freehand technique, more objective elastography

methods have been designed, such as shear wave elastography (SWE), which provides a quantitative measure of the intrinsic tissue elasticity using the acoustic push-pulse. SWE may improve the reproducibility of elastography data, although there are few published studies on the topic to date (Hudson et al. 2013; Koo et al. 2014; Suh et al. 2014). Fourth, echovariation is not a direct variable we can obtain from the ultrasonographic device and requires extra time for computer analysis, so it is difficult to use in clinical practice. However, we agree with Wu et al (2011) in that the procedure is not complicated and may provide more objective interpretation of the color distribution than visual grading. Finally, the reliability of image interpretation was not measured in this study, the primary aim of which was to examine the reliability of performing sonoelastography, so we relied on previous studies to design our image analysis protocol. These studies reported RTSE to be reliable in terms of visual grade system interpretation for musculoskeletal pathology (Drakonaki et al. 2009; Sconfienza et al. 2013; Wu et al. 2011) and also for quantitative analysis of the color histogram (Wu et al. 2011).

Conclusions

Real-time sonoelastography with quantitative analysis of echovariation can be a useful objective method for the evaluation of plantar fascia pathology. Quantitative analysis revealed that the intensity of green and blue components was significantly higher in the healthy group and the echovariation of the color red was higher in the affected fascia group. Further investigation in terms of how RTSE can be implemented in clinical daily practice is needed.

Uncited Reference

Gibbon and Long, 1999.

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Query: Please check edits made to short title and amend if necessary.
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