

Sonographic Evaluation of the Plantar Heel in Asymptomatic Endurance Runners

Mederic M. Hall, MD, Jonathan T. Finnoff, DO, Yusef A. Sayeed, MD, MPH, MEng, Jay Smith, MD

Objectives—The primary purpose of this investigation was to determine the prevalence and spectrum of asymptomatic sonographically determined structural changes in the plantar fascia and plantar heel pad among experienced runners without a history of heel pain.

Methods—Thirty-nine asymptomatic runners without a history of plantar heel pain were recruited. The following sonographic measures were recorded: power Doppler sonography in the plantar heel pad and plantar fascia, echo texture of the plantar heel pad, uncompressed heel pad thickness, compressed heel pad thickness, heel pad compressibility index, plantar fascia thickness, and plantar fascia echo texture.

Results—Doppler flow was shown in the plantar heel pads of 88% (68 of 77) of heels and 92% (36 of 39) of runners. Heel pad echo texture abnormalities were found in 86% (66 of 77) of heels and 97% (38 of 39) of runners. Mean values for right and left uncompressed heel pad thickness were 13.8 and 13.7 mm, respectively. The mean heel pad compressibility indices were 0.51 for the right heel and 0.53 for the left heel. Eight percent (6 of 77) of fat pads in 10% (4 of 39) of runners had abnormal compressibility indices. Doppler flow was present in the plantar fascia in 31% (24 of 77) of heels and 44% (17 of 39) of runners. The mean plantar fascia thicknesses were 3.78 mm for the right and 3.87 mm for the left. Forty-eight percent (37 of 77) of heels had an abnormal plantar fascia echo texture.

Conclusions—At least 1 potentially abnormal sonographic finding was present in each heel of all asymptomatic runners in this study. Consequently, sonographic abnormalities in the plantar heel should be interpreted within the clinical context when evaluating runners.

Key Words—foot; heel; musculoskeletal ultrasound; running; sonography

Received December 31, 2014, from the Department of Orthopedics and Rehabilitation, University of Iowa Sports Medicine, Iowa City, Iowa USA (M.M.H.); Departments of Physical Medicine and Rehabilitation (J.T.F., J.S.), Radiology (J.S.), and Anatomy (J.S.), Mayo Clinic College of Medicine, Mayo Clinic Sports Medicine Center, Rochester, Minnesota USA; and Department of Emergency Medicine, West Virginia University, Morgantown, West Virginia USA (Y.A.S.). Revision requested January 22, 2015. Revised manuscript accepted for publication January 27, 2015.

Address correspondence to Mederic M. Hall, MD, Department of Orthopedics and Rehabilitation, University of Iowa Sports Medicine, 2701 Prairie Meadow Dr, Iowa City, IA 52242 USA.

E-mail: mederic-hall@uiowa.edu

Abbreviations

BMI, body mass index

doi:10.7863/ultra.14.12073

Plantar heel pain is a common condition affecting endurance runners and accounts for approximately 8% of all running-related injuries.¹ Although plantar fasciitis is the most common cause of heel pain in the athletic population,^{2,3} the differential diagnosis of heel pain is broad and includes plantar heel pad syndrome (also referred to as fat pad syndrome), calcaneal fractures, regional nerve entrapments (eg, Baxter nerve), and referred pain syndromes.² The role of musculoskeletal sonography in the evaluation of plantar heel pain has been well established with respect to the plantar fascia.^{3–15} More specifically, plantar fascia thickening (>4 mm), hypoechogenicity, heterogeneity, and neovascularization are considered reliable markers of symptomatic plantar fasciitis, whereas a normal-appearing plantar fascia warrants consideration of alternative causes of heel pain.^{1,3,4,9,12–14} On the contrary, the role of sonography

in the evaluation of the plantar heel pad has received little attention, despite the recognition that the plantar heel pad can be a primary source of heel pain.

The plantar heel pad provides shock absorption for the calcaneus and is composed of closely packed chambers of specialized fat surrounded by tough circular or cone-shaped septa of collagen and elastin fibers.^{7,15–19} Structurally, the heel pad is arranged into a superficial microchamber and a deep macrochamber, which are separated by a fibrous layer referred to as the internal cup of the heel.²⁰ Consequently, the sonographic appearance of the normal heel pad is best described as a pattern of uniform heterogeneity in which circular or ovoid hypoechoic fat pockets are separated by hyperechoic fibrous septa. Plantar heel pad syndrome refers to pain arising from the plantar heel pad secondary to disruption of the fatty architecture. Damage to the plantar heel pad typically results from acute traumatic or cumulative microtraumatic mechanical injury but may also occur in the setting of systemic inflammatory disease. Regardless of etiology, the architectural changes within the heel pad may result in pain secondary to reduced or unequal shock absorption.^{6,7,15,16}

Although prior studies have attempted to characterize the sonographic properties of the plantar heel pad and their relationship with dysfunction and pain, there are no universally recognized sonographic criteria for defining a normal heel pad. Previous investigators have associated an “inflammatory-edematous” sonographic pattern with primary heel pad pain in rheumatologic populations, consisting of increased heterogeneity and marked hypoechogenicity within the subcalcaneal hypodermal tissue, loss of the characteristic lobular structure with interruption of the hyperechoic septa and occasional anechoic fluid-filled cavities, increased plantar heel pad thickness (defined as >21 mm), increased plantar heel pad compressibility ($>40\%$ reduction in heel pad thickness with manual compression), and flow on power Doppler sonography.^{6,7} The same group also described a “non-inflammatory degenerative-atrophic pattern” more commonly associated with plantar fasciopathy, consisting of increased echogenicity with hyperechoic foci and occasionally associated with a thin heel pad (<12 mm) or reduced compressibility ($<40\%$ reduction in heel pad thickness).⁷ Multiple investigations have also reported sonographically derived values for uncompressed heel pad thickness (12–28 mm; average value, 18 mm) and heel pad compressibility (heel pad compressibility index = compressed heel pad thickness divided by the uncompressed heel pad thickness; normal range, 0.45–0.75).¹⁵

During routine ankle-foot sonographic examinations of runners without a history of heel pain syndromes, we

have encountered structural “abnormalities” in both the plantar fascia and plantar heel pad. We hypothesized that the cumulative impact of running may induce asymptomatic structural changes in the heel region. Although asymptomatic structural changes have been reported in a variety of body regions, to our knowledge, no prior investigation has systematically evaluated the plantar heel region in asymptomatic runners, a group at risk for developing heel abnormalities.^{21–35} Consequently, the primary purpose of this investigation was to determine the prevalence and spectrum of asymptomatic sonographically determined structural changes in the plantar fascia and plantar heel pad among experienced runners without a history of heel pain. On the basis of our preliminary observations, we hypothesized that more than 50% of asymptomatic runners would have at least 1 structural abnormality in 1 heel, as defined by the following: (1) presence of vascularization on power Doppler sonography, (2) nonuniform heterogeneous echo texture of the plantar heel pad, (3) abnormal plantar heel pad thickness (uncompressed heel pad thickness <12 or >28 mm),^{15,36} (4) abnormal plantar heel pad compressibility (heel pad compressibility index <0.45 or >0.75),¹⁵ (5) abnormal plantar fascia thickness (>4 mm),¹ and (6) abnormal plantar fascia echo texture.

Materials and Methods

Participants

Thirty-nine asymptomatic male and female volunteers 20 to 67 years of age with an average running mileage of at least 15 miles per week for 6 months before study entry were recruited to voluntarily participate. The study protocol was approved by the Mayo Clinic Institutional Review Board. Informed consent was obtained, and participants were assigned an identification number for data analysis purposes. The following exclusion criteria were applied: (1) current plantar heel pain in either foot or history of plantar heel pain requiring medical evaluation, (2) history of rheumatologic disease or diabetes, and (3) history of hind foot surgery on either side. Age, sex, weight, and height were recorded, and the body mass index (BMI) was calculated for each participant. Average weekly running mileage and shoe type preference (minimalistic/barefoot, cushioned, stability, or motion control) was recorded.

Sonographic Measurements

All measurements were completed on a CX50 ultrasound machine with a 12–3-MHz linear array transducer (Philips Healthcare, Bothell, WA). The primary investigator (M.M.H.) obtained all sonograms and performed all

relevant measurements. Qualitative interpretation of the recorded images was then performed independently by each of the 3 study coinvestigators (M.M.H., J.T.F., and J.S., who had greater than 3, 4, and 7 years of experience performing musculoskeletal sonography, respectively, at the time of this investigation), and in the setting of differing opinions, a consensus interpretation was reached.

Sonographic examinations were performed at an interval of at least 12 hours after the most recent running or impact exercise session. Participants were instructed to lie prone with their feet hanging free over the end of the examination table (Figure 1A). The plantar aspects of both heels were scanned in the same position in a random order. Power Doppler sonographic measurements were obtained first to avoid any alterations in the presence or degree of flow that could be due to compression or transducer manipulation involved in the other measurements.³⁷ The ankle was placed in a relaxed position, and care was taken to avoid compression while power Doppler sonograms were acquired, both of which could affect flow detection. The transducer was swept from the medial to lateral aspect of the plantar heel in an anatomic sagittal plane while power Doppler sonograms were recorded. The same process was

then performed in an anatomic coronal plane moving proximal to distal, beginning at the proximal plantar aspect of the calcaneus and ending just past the anterior aspect of the calcaneus. Doppler parameters were set at a pulse repetition frequency of 0.8 kHz, a low filter setting, and optimization for low flow detection. Gain was adjusted to the highest level achievable without background noise. The presence of neovascularity was identified as occurring in the plantar heel pad, the plantar fascia, or the underlying calcaneus. The intensity was graded semiquantitatively using the modified Ohberg score¹⁷ as follows: (1) grade 0, no vascularization; (2) grade 1+, 1 vessel; (3) grade 2+, 2 vessels; (4) grade 3+, 3 vessels; and (5) grade 4+, more than 3 vessels.

Next, the echo texture of the plantar heel pad was assessed by using a long-axis orientation relative to the underlying plantar fascia. Long-axis images were saved at 3 sites corresponding to the medial, central, and lateral aspects of the heel pad. These sites were determined by drawing a sagittally oriented line at the midpoint of the heel (central site) and then a medial line (medial site) and lateral line (lateral site) halfway between the central line and the medial and lateral aspects of the heel, respectively (Figure 1B).

Figure 1. A. Participants were positioned prone with feet hanging free over the edge of the examination table for all measurements. **B.** Measurements were recorded at predetermined locations corresponding to the central, medial, and lateral thirds of the plantar heel.



As discussed above, whereas the “normal” sonographic appearance of the plantar heel pad has not been formally documented, prior investigators have described the sonographic appearance of the heel pad as being uniformly heterogeneous with hyperechoic septa interposed between lobular hypoechoic fat regions.^{7,16,18,19} For the purpose of this study, any loss of this uniform appearance was considered abnormal. When present, the appearance and location of specific lesions were recorded (ie, more organized focal hypoechoic areas or anechoic cystic fluid collections).

The plantar heel pad’s thickness and compressibility were measured with the transducer placed in a sagittal plane over the midportion of the plantar heel pad. The following measurements to the nearest tenth of a millimeter were completed by using the ultrasound machine’s electronic digital calipers¹⁵: (1) uncompressed heel pad thickness, which was the shortest distance between the midplantar calcaneus and the skin surface (the transducer was “floated” over the plantar surface of the calcaneus using acoustic-coupling gel to ensure that the heel pad remained uncompressed); (2) compressed heel pad thickness, which was the shortest distance between the midplantar calcaneus and the skin surface during maximal manual heel pad compression by the transducer; and (3) heel pad compressibility index, which was the compressed heel pad thickness divided by the uncompressed heel pad thickness.

After evaluation of the heel pad for nonuniformity, the plantar fascia was evaluated in its long axis. The transducer was placed over the region of maximal thickness, and the thickness of the plantar fascia measured to the nearest tenth of a millimeter by using the ultrasound machine’s electronic digital calipers. Thereafter, the sonographic appearance of the plantar fascia was graded as follows: (1) grade 0, normal; (2) grade 1a, hypoechogenicity affecting less than one-third of the fascia depth; (3) grade 1b, hypoechogenicity affecting between one-third and two-thirds of the fascia depth; (4) grade 1c, hypoechogenicity affecting greater than two-thirds of the fascia depth; (5) grade 2, partial-thickness tear (focal anechoic region confirmed on an orthogonal short-axis view); and (6) grade 3, full-thickness tear (full-thickness defect in the fascia confirmed on an orthogonal short-axis view).³⁸

Statistical Analysis

Descriptive statistics were used to report the demographic data, including height, weight, BMI, and age. Descriptive statistics were also used to report categorical data, including shoe type, average mileage, plantar fascia echo texture, and Doppler flow; and quantitative data, including the left and right uncompressed heel pad thickness, compressed heel pad thickness, heel pad compressibility index, and plantar fascia thickness. Left-right comparisons were performed with a standard 2-sample *t* test. JMP statistical software (SAS Institute Inc, Cary, NC) was used for all statistical analyses.

Results

Demographics

Demographic data are presented in Table 1 and Figure 2. The means and standard deviations quantified the demographics appropriately without any significant outliers. The most popular shoe type was cushioned, followed by stability (Table 2). Only 1 athlete ran barefoot; none ran with a minimalist shoe; and 2 wore motion control shoes. Nine participants (23%) ran greater than 40 miles per week, with most (44%) running between 25 and 35 miles per week on average during the 6 months before study participation (Table 3).

Plantar Heel Pad

Doppler flow was shown in the plantar heel pads of 88% (68 of 77) of heels and 92% (36 of 39) of runners (Figure 3 and Table 4). More than 50% (41 of 77) of heels with Doppler flow were grade 2+.

Heel pad echo texture abnormalities were common, with only 14% (11 of 77) of all heels showing a normal echo texture throughout the heel pad (Figure 4 and Table 5). Furthermore, only 1 runner had normal echo texture findings throughout both right and left heel pads. When evaluated by region, 34% (26 of 77) of heels showed echo texture abnormalities within the medial region, 56% (43 of 77) within the central region, and 60% (46 of 77) within the lateral region. A variety of nonuniformities were seen, ranging from focal or diffuse regions of variable hypoechogenicity

Table 1. Demographic Data for Asymptomatic Endurance Runners

Sex (n)	Height, cm	Weight, kg	BMI, kg/m ²	Age, y
Male (20)	176.2 (152.4–190.5)	72.0 (58.1–86.1)	22.8 (19.5–26.4)	45.2 (26–67)
Female (19)	166.0 (157.5–177.8)	59.7 (52.2–70.3)	21.6 (18.7–25.0)	33.0 (20–57)
Total (39)	171.2 (152.4–190.5)	66.0 (52.2–88.2)	22.2 (18.7–26.4)	39.3 (20–67)

Height, weight, BMI, and age are presented as mean (range).

(contusive pattern) to discrete linear clefts resembling “fat fractures.”²⁸ Of note, all abnormalities were observed within the deep 80% of the heel pad.

Heel pad thickness and compressibility data are presented in Table 6. Mean values for right and left uncompressed heel pad thickness were 13.8 mm (range, 10.5–16.9 mm) and 13.7 mm (range, 10.4–17.0 mm), respectively (normal range, 12–28 mm; average, 18 mm^{15,36}). Female participants had a thinner uncompressed heel pad thickness than male participants, in agreement with prior studies.³⁹ Seven percent (5 of 77) of uncompressed heel pad thicknesses in 5% (4 of 39) of runners were less than 12 mm, and none were greater than 28 mm. The mean heel pad compressibility indices were 0.51 (range, 0.35–0.60) for the right heel and 0.53 (range 0.42–0.64) for the left heel (normal heel pad compressibility index, <0.45 or >0.75¹⁵). Eight percent (6 of 77) of heel pads in 10% (4 of 39) of runners had abnormal

compressibility indices. All abnormal heel pads had a heel pad compressibility index of less than 0.45, whereas none were greater than 0.75.

Plantar Fascia

Doppler flow was present in the plantar fascia in 31% (24 of 77) of heels, with 44% (17 of 39) of runners showing Doppler flow in at least 1 plantar fascia (Table 7). Most plantar fascias showing Doppler flow were grade 1+.

The mean plantar fascia thicknesses were 3.78 mm (range, 2.4–7.0 mm) for the right and 3.87 mm (range, 2.3–6.7 mm) for the left (Figure 5 and Table 8). A large variation in thicknesses was observed, as shown in Figure 6. When using a cut-off of 4 mm, 35% (27 of 77) of heels among 41% (16 of 39) of runners showed an abnormally thickened plantar fascia.¹ Fifty-two percent (40 of 77) of plantar fascias showed a normal sonographic echo texture (Table 9). The remaining 48% (37 of 77) of heels showed variable structural abnormalities, ranging from mild regions of hypoechogenicity to partial-thickness tears. Four per-

Figure 2. Age distribution.

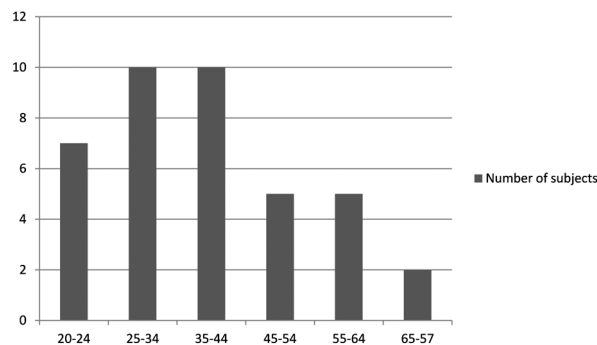


Table 2. Shoe Type

Sex	Barefoot	Cushion	Motion Control	Stability
Male	0	12	1	7
Female	1	10	1	7
Total	1	22	2	14

Table 3. Average Weekly Running Mileage

Sex	Miles/wk					
	15–19	20–24	25–29	30–34	35–39	40+
Male	1	2	2	6	3	6
Female	2	4	5	4	1	3
Total	3	6	7	10	4	9

Values represent average weekly mileage during the 6 months before study participation.

Figure 3. Power Doppler sonogram of the heel fat pad. Box indicates area evaluated by power Doppler sonography; and red and yellow inside the box, presence of vasculature in the heel fat pad. The transducer was oriented in the anatomic sagittal plane. Top indicates superficial; bottom, deep; left, proximal; and right, distal.

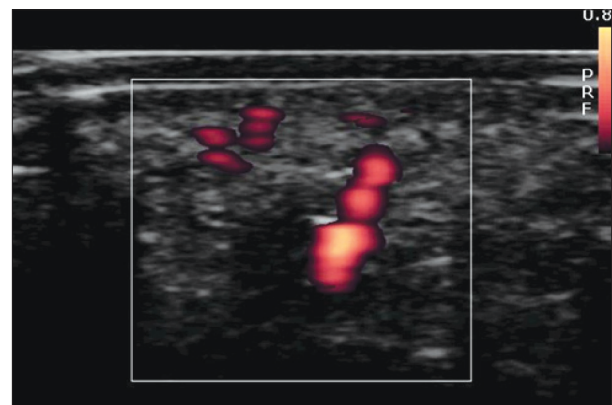


Table 4. Doppler Signal in the Heel Fat Pad

Side	Grade				
	0	1+	2+	3+	4+
Right (n = 38)	5	8	21	3	1
Left (n = 39)	4	12	20	3	0
Total (n = 77)	9	20	41	6	1

Grade 0 indicates no vascularization; grade 1+, 1 vessel; grade 2+, 2 vessels; grade 3+, 3 vessels; and grade 4+, more than 3 vessels.

Figure 4. Heel fat pad. **A**, Normal heel fat pad with uniform heterogeneity and hyperechoic septa interposed between lobular hypoechoic fat regions (arrows). **B**, Contusive pattern of heel fat pad abnormality with diffuse hypoechoogenicity (arrows). **C**, Variant contusive pattern with focal hypoechoic regions (arrows). **D**, Fracture pattern of heel fat pad abnormality. Note distinct vertically oriented hypoechoic regions extending through the heel fat pad (boxes). For all images, the transducer was oriented in the anatomic sagittal plane. Top indicates superficial; bottom, deep; left, proximal; and right, distal.

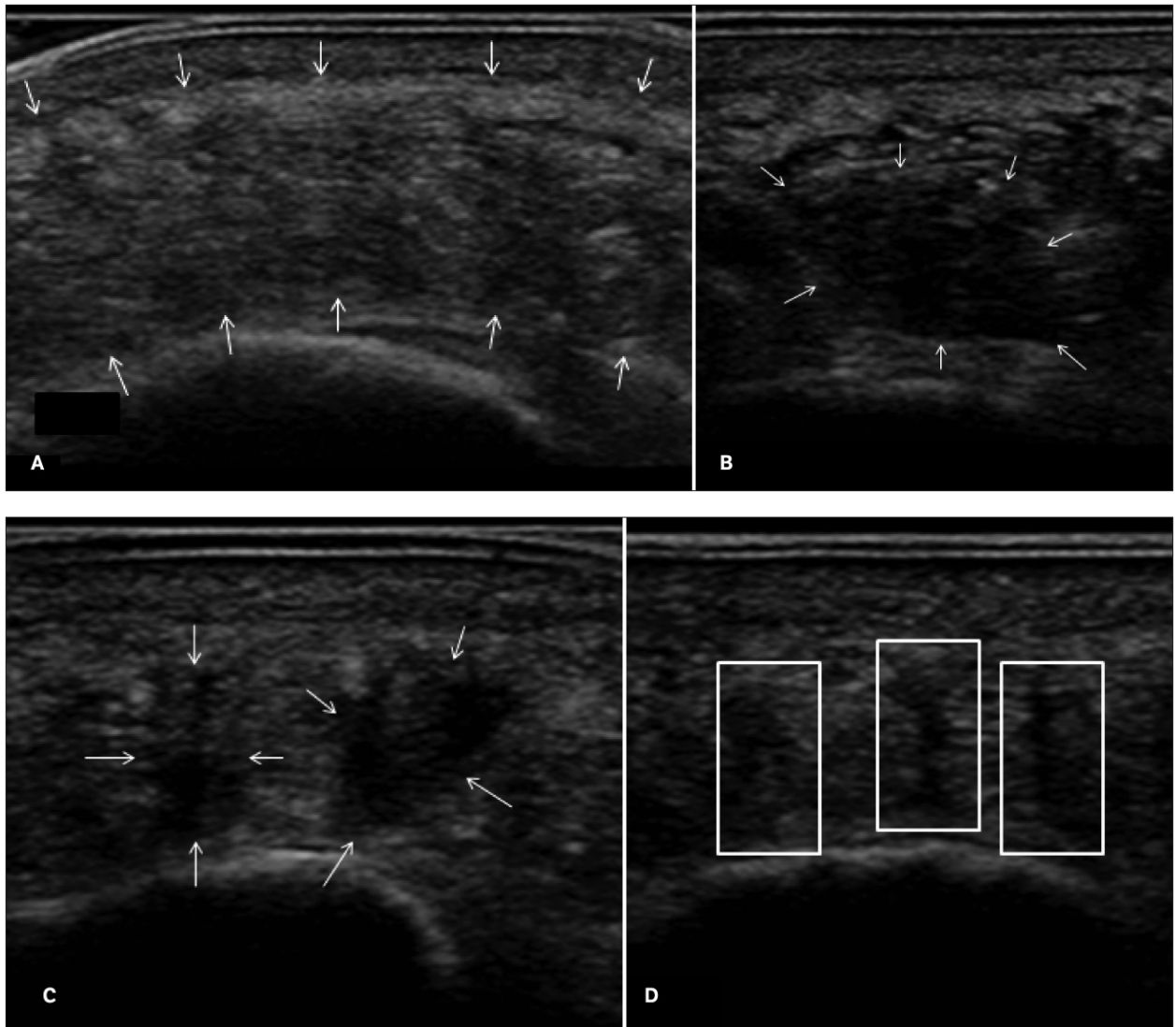


Table 5. Sonographic Appearance of the Plantar Heel Pad (n = 77 Heels)

Appearance	Medial	Central	Lateral
Normal	51 (R = 24; L = 27)	34 (R = 17; L = 17)	31 (R = 12; L = 19)
Abnormal	26 (R = 14; L = 12)	43 (R = 21; L = 22)	46 (R = 26; L = 20)

Medial indicates midway between the midline of the heel and the medial edge of the heel; central, midline of the heel; lateral, midway between the midline of the heel and the lateral edge of the heel; normal, uniformly heterogeneous with hyperechoic septa interposed between lobular hypoechoic fat regions; abnormal, any sonographically apparent change in the normal fat pad appearance (eg, large hypoechoic or hyperechoic regions); L, left; and R, right.

cent (3 of 77) of heels showed an abnormal plantar fascia thickness (>4 mm) but a normal echo texture, whereas 17% (13 of 77) showed an abnormal plantar fascia echo texture but a normal thickness (Table 10). Of the 24 heels that contained power Doppler flow within the plantar fascia, 38% (9 of 24) were found to have a normal echo texture; 42% (10 of 24) had a normal thickness; and 25% (6 of 24) had both a normal thickness and echo texture (Table 11).

Discussion

To our knowledge, this study is the first systematic sonographic evaluation of the plantar heel region in asymptomatic, endurance runners, a population identified in previous investigations to be at high risk for heel pain.^{1,3} The findings of this investigation confirmed our hypothesis that a large proportion of runners have sonographically apparent structural abnormalities in the plantar heel pad or plantar fascia. In fact, based on the criteria used for this investigation, all runners (39) showed at least 1 sonographic

abnormality within either the plantar heel pad or plantar fascia of each heel evaluated. Of the 77 heels examined, 99% (76) had abnormal plantar heel pads; 60% (46) had abnormal plantar fascias, 58% (45) had abnormalities in both the plantar fascia and plantar heel pad, and 91% (70) had Doppler flow within either the plantar heel pad or plantar fascia. Consequently, our findings have important clinical implications when interpreting structural findings in runners presenting with heel pain syndromes.

The presence of neovascularization and its association with symptoms within the musculoskeletal system is a topic of much debate. Although several studies have reported a correlation between neovascularization and tendon pain,^{21,23,24,26} other studies have not found such a relationship.^{22,25,29} No prior studies have systematically

Figure 5. Long-axis (longitudinal) views of the plantar fascia. **A**, Normal plantar fascia with a hyperechoic fibrillar pattern (thickness, 3.45 mm). **B**, Abnormal plantar fascia with thickening (7 mm), hypoechogenicity, and heterogeneity. For both images, the transducer was oriented in the anatomic sagittal plane. Arrows indicate plantar fascia; crosses, electronic measurement calipers; top, superficial; bottom, deep; left, proximal; and right, distal.

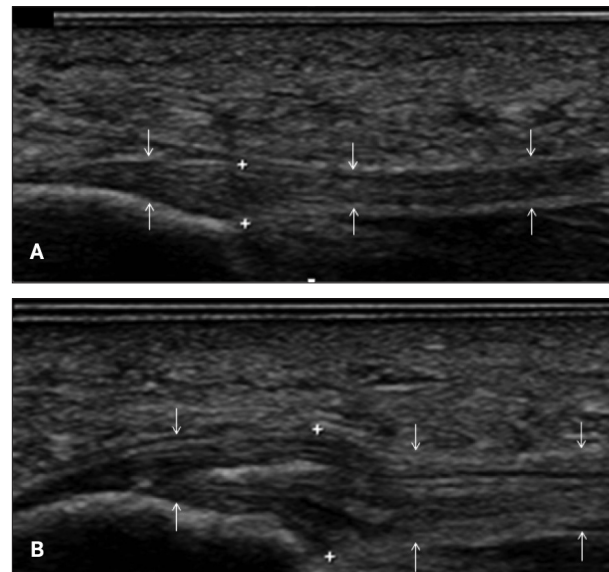


Table 6. Plantar Heel Pad Thickness (n = 77 Heels)

Measurement Condition	Side	Thickness, mm		
		Mean	SD	Range
Male				
UCHPT	Right	1.396	0.162	1.05–1.69
	Left	1.399	0.171	1.04–1.70
CHPT	Right	0.725	0.098	0.535–0.941
	Left	0.717	0.187	0.081–1.01
HPCI	Right	0.520	0.041	0.43–0.60
	Left	0.534	0.053	0.45–0.64
Female				
UCHPT	Right	1.364	0.131	1.10–1.61
	Left	1.344	0.131	1.061–1.560
CHPT	Right	0.688	0.092	0.512–0.952
	Left	0.695	0.110	0.546–0.991
HPCI	Right	0.506	0.058	0.35–0.59
	Left	0.516	0.056	0.42–0.64

UCHPT indicates uncompressed heel pad thickness; CHPT, compressed heel pad thickness; and HPCI, heel pad compressibility index.

Table 7. Doppler Signal in the Plantar Fascia

Side	Grade				
	0	1+	2+	3+	4+
Right (n = 38)	27	9	2	0	0
Left (n = 39)	26	8	5	0	0
Total (n = 77)	53	17	7	0	0

Grades are as in Table 4.

Table 8. Plantar Fascia Thickness (n = 77 Heels)

Sex	Side	Thickness, mm		
		Mean	SD	Range
Male	Right	0.387	0.085	0.301–0.603
	Left	0.392	0.097	0.228–0.655
Female	Right	0.367	0.108	0.240–0.704
	Left	0.382	0.101	0.267–0.579

evaluated the plantar heel pad for vascularization in an asymptomatic population of distance runners. Falsetti et al⁶ described intense vascularization of inflammatory-edematous lesions of the heel pad in patients with rheumatoid arthritis. The flow was observed to decrease in response to anti-tumor necrosis factor α treatment, suggesting that this appearance represented an inflammatory response. It is unlikely that our population of asymptomatic runners with no history of rheumatologic disease had an inflammatory response within their heel pads. Consequently, it is likely that the positive Doppler findings in our runners reflect normal adaptive changes to chronic mechanical stresses, although the possibility of Doppler flow representing a preclinical condition cannot be excluded. Although the etiology of such vascularity within the heel pad remains unknown, given the high prevalence within our asymptomatic population, we would caution against interpreting the presence of power Doppler flow as a pathologic finding.

The mean uncompressed plantar heel pad thickness among our asymptomatic runners was smaller than the previously reported mean value of 18 mm but still within previously reported normal ranges (12–28 mm^{15,36}). Only 5 heels in 4 runners had heel pads smaller than 12 mm. No heels were thicker than the upper limit of normal (28 mm). Ninety-two percent (71 of 77) of heels had normal compressibility, as defined by heel pad compressibility indices between 0.45 and 0.75. Of the remaining 8% (6 of 77), all had increased compressibility (ie, decreased stiffness), with heel pad compressibility indices of less than 0.45. Studies have demonstrated an association between both increased and decreased heel pad stiffness and plantar heel pain.^{16,40,41} Given that the presumed function of the heel pad is to act as a shock-absorbing structure, compressibility likely plays a key role in proper heel pad

function. Consequently, our findings suggest that although our participants had slightly thinner heel pads than expected (although still within the normal range), the compressibility, and likely function, was normal.

Despite the observation that most of our runners had a normal uncompressed heel pad thickness and heel pad compressibility index, sonographically detectable structural changes were present in the most heel pads. Overall, 86% (66 of 77) of heel pads showed some echo texture abnormality. These changes ranged from focal hypoechoic regions within part of the heel pad to more diffuse hypoechoic or anechoic regions involving nearly the entire heel pad (Figure 4). As the sonographic appearance of the plantar heel pad has not been systematically studied in prior investigations, we are unable to compare our results with previously collected data. However, many of the structural abnormalities documented among our runners have been described in symptomatic populations with systemic inflammatory disorders.^{6,7} As a history of rheumatologic disorders was an exclusion criterion, we postulate that these changes observed among our runners may represent the sequelae of repetitive contusive injury with disruption of the normal fibrofatty architecture of the heel pad. Sonographically, these changes may appear on a continuum ranging from focal hypoechoic regions to more diffuse involvement. In 33% (25 of 77) of heels, we also observed more discrete, vertically oriented hypoechoic clefts within the heel pad (Figure 4D). We hypothesize that this finding may represent a “fat fracture,” as previously described by Thomas et al.²⁸ Fat fractures are thought to occur secondary to shear stress through fatty tissue, and such shear stress may be anticipated to occur in the plantar heel pad during running. Both the “contusive” and fat fracture patterns were frequently seen within the same heel pad and even within the same region of the heel pad. However, without histologic validation, the nature of the

Figure 6. Plantar fascia thickness (n = 77 heels).

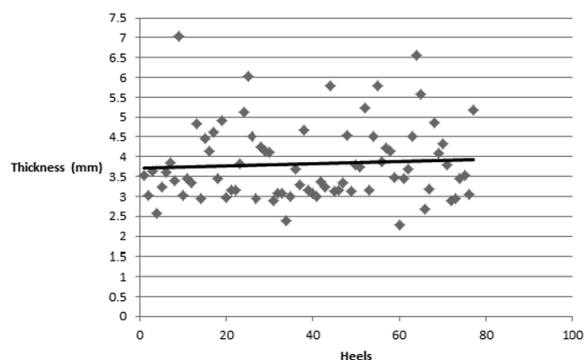


Table 9. Plantar Fascia Echo Texture (n = 77 Heels)

Sex	Grade					
	0	1a	1b	1c	2	3
Male	19	10	6	2	3	0
Female	21	5	2	3	6	0
Total (%)	40 (52)	15 (19)	8 (10)	5 (6)	9 (12)	0

Grade 0 indicates normal; grade 1a, hypoechoogenicity affecting less than one-third of the fascia depth; grade 1b, hypoechoogenicity affecting between one-third and two-thirds of the fascia depth; grade 1c, hypoechoogenicity affecting greater than two-thirds of the fascia depth; grade 2, partial-thickness tear; and grade 3, full-thickness tear.

observed structural heel pad changes among our asymptomatic runners remains indeterminate.

The distribution of heel pad abnormalities warrants further discussion. Abnormalities were more prevalent in the lateral and central regions of the heel pad compared to the medial region. One could hypothesize that this distribution may be partly due to the normal progression from the posterolateral heel to the medial forefoot during the loading phase of a typical heel strike running gait. Also of interest, no abnormalities were noted within the superficial 20% of the fat pad. This lack of abnormalities appears to correlate with the superficial microchamber of the heel pad. It is unclear why the deep macrochamber would be more susceptible to these changes; however, contusive forces are known to primarily involve the deeper layers in other regions of the body (ie, quadriceps contusion), and this finding may represent a similar pattern of injury. Due to the paucity of abnormalities in the medial and superficial aspects of the plantar heel pad in this asymptomatic population of runners, sonographic abnormalities in these areas in a symptomatic individual may be more indicative of injury. Further investigation is required to corroborate this theory.

Doppler flow within the plantar fascia has been promoted as a specific finding for symptomatic plantar fasciitis. Although some investigations have demonstrated an association between Doppler flow and symptomatic plantar fasciitis, others have demonstrated Doppler flow in a small percentage of asymptomatic individuals (5%–7%).^{42,43} However, to our knowledge, no prior investigation has

specifically focused on runners. Forty-four percent (17 of 39) of runners in this investigation had Doppler flow within the plantar fascia. Similar to the plantar heel pad, this finding likely represents an adaptive response to chronic mechanical loading, but preclinical changes cannot be excluded, and further investigation is warranted in this population.

Plantar fascia thickness of greater than 4 mm has been suggested as diagnostic for plantar fasciitis.¹ Among our asymptomatic runners, 35% had plantar fascia thicknesses above this threshold, with some asymptomatic athletes measuring greater than 7 mm (Figure 6). Only 1 prior study assessed the influence of athletic activity on plantar fascia thickness in a mixed population (ie, not strictly runners) of healthy asymptomatic young adults aged 20 to 30 years.⁴⁴ The authors found no differences in the thickness of the plantar fascia with increasing activity levels. Our investigation included older individuals (age range, 20–67 years), and the cumulative effects of age and repetitive loading from running may partly explain this percentage of abnormally thickened plantar fascias.

Even more common than increased thickness were sonographically apparent structural abnormalities. Nearly half of the evaluated heels were found to have some degree of abnormality within the plantar fascia, with 12% having partial-thickness tears (Table 9).

There were several limitations to this study. First, the small sample size and heterogeneity with respect to age, footwear preference, and weekly running mileage may limit the generalizability of our results. However, the study was designed to recruit a representative group of endurance runners similar to what may be seen in a community sports medicine practice. Second, the histologic correlates of the findings are unknown. It is unclear whether these asymptomatic changes represent substantial pathologic changes within the runners' heels. Further research is required to answer this question. Since this study used a cross-sectional design and did not follow the participants prospectively, it is unknown whether the sonographic abnormalities found in this study predispose to the future development of heel pain or are simply adaptive responses to prolonged training. Although studies have suggested that similar changes in the Achilles tendon prognosticate the future development of symptomatic Achilles tendinopathy in selected populations,⁴⁵ prospective studies are needed to determine whether these abnormalities provide prognostic information for the plantar heel. Third, a general limitation of a cross-sectional study is that we were unable to assess any change in the plantar heel structures over time. It is not unreasonable to expect these tissues to be dynamic, and findings may change

Table 10. Plantar Fascia Echo Texture and Thickness (n = 77 Heels)

Thickness	Echo Texture, n (%)	
	Normal	Abnormal
Normal (≤4 mm)	37 (48) (R = 19; L = 18)	13 (17) (R = 6; L = 7)
Abnormal (>4 mm)	3 (4) (R = 1; L = 2)	24 (31) (R = 12; L = 12)

L indicates left, and R, right.

Table 11. Plantar Fascia Echo Texture and Thickness in Participants With Plantar Fascia Vascularity (n = 24)

Thickness	Echo Texture, n (%)	
	Normal	Abnormal
Normal (≤4 mm)	6 (25) (R = 4; L = 2)	4 (16) (R = 1; L = 3)
Abnormal (>4 mm)	3 (13) (R = 1; L = 2)	11 (46) (R = 5; L = 6)

L indicates left; and R, right.

over time and in relation to activity or other factors. Serial investigations over time and in relation to factors, such as running mileage, terrain, footwear, and BMI, may provide further insight.

In conclusion, at least 1 potentially abnormal sonographic finding was present in each heel of all asymptomatic runners in this study. Consequently, B-mode and Doppler abnormalities in the plantar heel pad and plantar fascia should always be considered within the clinical context when evaluating runners with heel pain syndromes. Plantar heel pad thickness and compressibility were largely normal, and structural abnormalities were less common in the medial region of the heel pad and absent in the superficial region. Abnormal findings in these locations may have more clinical importance, but further studies are required to confirm this hypothesis.

References

- McMillan AM, Landorf KB, Barrett JT, Menz HB, Bird AR. Diagnostic imaging for chronic plantar heel pain: a systematic review and meta-analysis. *J Foot Ankle Res* 2009; 2:32.
- Brukner P, Khan K. Foot pain. In: Brukner P, Khan K (eds). *Clinical Sports Medicine*. New York, NY: McGraw-Hill Education; 2009:646–672.
- Cardinal E, Chhem RK, Beauregard CG, Aubin B, Pelletier M. Plantar fasciitis: sonographic evaluation. *Radiology* 1996; 201:257–259.
- Akfiat M, Sen C, Günes T. Ultrasonographic appearance of the plantar fasciitis. *Clin Imaging* 2003; 27:353–357.
- Cunnane G, Brophy DP, Gibney RG, FitzGerald O. Diagnosis and treatment of heel pain in chronic inflammatory arthritis using ultrasound. *Semin Arthritis Rheum* 1996; 25:383–389.
- Falsetti P, Frediani B, Acciai C, et al. Ultrasonography and magnetic resonance imaging of heel fat pad inflammatory-oedematous lesions in rheumatoid arthritis. *Scand J Rheumatol* 2006; 35:454–458.
- Falsetti P, Frediani B, Acciai C, Baldi F, Filippou G, Marcolongo R. Heel fat pad involvement in rheumatoid arthritis and in spondyloarthropathies: an ultrasonographic study. *Scand J Rheumatol* 2004; 33:327–331.
- Kane D, Greaney T, Shanahan M, et al. The role of ultrasonography in the diagnosis and management of idiopathic plantar fasciitis. *Rheumatology (Oxford)* 2001; 40:1002–1008.
- Karabay N, Toros T, Hurel C. Ultrasonographic evaluation in plantar fasciitis. *J Foot Ankle Surg* 2007; 46:442–446.
- Ozdemir H, Yilmaz E, Murat A, Karakurt L, Poyraz AK, Ogur E. Sonographic evaluation of plantar fasciitis and relation to body mass index. *Eur J Radiol* 2005; 54:443–447.
- Pascual Huerta J, García JM, Matamoros EC, Matamoros JC, Martínez TD. Relationship of body mass index, ankle dorsiflexion, and foot pronation on plantar fascia thickness in healthy, asymptomatic subjects. *J Am Podiatr Med Assoc* 2008; 98:379–385.
- Sabir N, Demirelenk S, Yagci B, Karabulut N, Cubukcu S. Clinical utility of sonography in diagnosing plantar fasciitis. *J Ultrasound Med* 2005; 24:1041–1048.
- Smith J, Finnoff JT. Diagnostic and interventional musculoskeletal ultrasound, part 2: clinical applications. *PMR* 2009; 1:162–177.
- Tsai WC, Chiu MF, Wang CL, Tang FT, Wong MK. Ultrasound evaluation of plantar fasciitis. *Scand J Rheumatol* 2000; 29:255–259.
- Uzel M, Cetinus E, Ekerbicer HC, Karaoguz A. Heel pad thickness and athletic activity in healthy young adults: a sonographic study. *J Clin Ultrasound* 2006; 34:231–236.
- Tong J, Lim C, Goh O. Technique to study the biomechanical properties of the human calcaneal heel pad. *Foot* 2003; 13:83–91.
- Sengkerij PM, de Vos RJ, Weir A, van Weelde BJ, Tol JL. Interobserver reliability of neovascularization score using power Doppler ultrasonography in midportion Achilles tendinopathy. *Am J Sports Med* 2009; 37:1627–1631.
- Hsu TC, Wang CL, Tsai WC, Kuo JK, Tang FT. Comparison of the mechanical properties of the heel pad between young and elderly adults. *Arch Phys Med Rehabil* 1998; 79:1101–1104.
- Rchallis JH, Murdoch C, Winter SL. Mechanical properties of the human heel pad: a comparison between populations. *J Appl Biomech* 2008; 24:377–381.
- Sarraffian SK, Kelikian AS. *Sarraffian's Anatomy of the Foot and Ankle*. 3rd ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2011.
- Alfredson H, Ohberg L, Forsgren S. Is vasculo-neural ingrowth the cause of pain in chronic Achilles tendinosis? An investigation using ultrasonography and colour Doppler, immunohistochemistry, and diagnostic injections. *Knee Surg Sports Traumatol Arthrosc* 2003; 11:334–338.
- Boesen AP, Boesen MI, Torp-Pedersen S, et al. Associations between abnormal ultrasound color Doppler measures and tendon pain symptoms in badminton players during a season: a prospective cohort study. *Am J Sports Med* 2012; 40:548–555.
- Divani K, Chan O, Padhiar N, et al. Site of maximum neovascularisation correlates with the site of pain in recalcitrant mid-tendon Achilles tendinopathy. *Man Ther* 2010; 15:463–468.
- du Toit C, Stieler M, Saunders R, Bisset L, Vicenzino B. Diagnostic accuracy of power Doppler ultrasound in patients with chronic tennis elbow. *Br J Sports Med* 2008; 42:872–876.
- Kardouni JR, Seitz AL, Walsworth MK, Michener LA. Neovascularization prevalence in the supraspinatus of patients with rotator cuff tendinopathy. *Clin J Sport Med* 2013; 23:444–449.
- Ohberg L, Alfredson H. Effects on neovascularisation behind the good results with eccentric training in chronic mid-portion Achilles tendinosis? *Knee Surg Sports Traumatol Arthrosc* 2004; 12:465–470.
- Silvis ML, Mosher TJ, Smetana BS, et al. High prevalence of pelvic and hip magnetic resonance imaging findings in asymptomatic collegiate and professional hockey players. *Am J Sports Med* 2011; 39:715–721.
- Thomas RH, Holt MD, James SH, White PG. "Fat fracture": a physical sign mimicking tendon rupture. *J Bone Joint Surg Br* 2001; 83:204–205.

29. van Snellenberg W, Wiley JP, Brunet G. Achilles tendon pain intensity and level of neovascularization in athletes as determined by color Doppler ultrasound. *Scand J Med Sci Sports* 2007; 17:530–534.
30. Connor PM, Banks DM, Tyson AB, Coumas JS, D'Alessandro DF. Magnetic resonance imaging of the asymptomatic shoulder of overhead athletes: a 5-year follow-up study. *Am J Sports Med* 2003; 31:724–727.
31. Flanigan DC, Harris JD, Trinh TQ, Siston RA, Brophy RH. Prevalence of chondral defects in athletes' knees: a systematic review. *Med Sci Sports Exerc* 2010; 42:1795–1801.
32. Fredericson M, Ho C, Waite B, et al. Magnetic resonance imaging abnormalities in the shoulder and wrist joints of asymptomatic elite athletes. *PMR* 2009; 1:107–116.
33. Hurd WJ, Eby S, Kaufman KR, Murthy NS. Magnetic resonance imaging of the throwing elbow in the uninjured, high school-aged baseball pitcher. *Am J Sports Med* 2011; 39:722–728.
34. Maurer M, Soder RB, Baldisserotto M. Spine abnormalities depicted by magnetic resonance imaging in adolescent rowers. *Am J Sports Med* 2011; 39:392–397.
35. Nicol AM, McCurdie I, Etherington J. Use of ultrasound to identify chronic Achilles tendinosis in an active asymptomatic population. *J R Army Med Corps* 2006; 152:212–216.
36. Prichasuk S, Mulpruek P, Siriwongpairat P. The heel-pad compressibility. *Clin Orthop Relat Res* 1994; 300:197–200.
37. Cook JL, Kiss ZS, Ptasznik R, Malliaras P. Is vascularity more evident after exercise? Implications for tendon imaging. *AJR Am J Roentgenol* 2005; 185:1138–1140.
38. Finnoff JT, Fowler SP, Lai JK, et al. Treatment of chronic tendinopathy with ultrasound-guided needle tenotomy and platelet-rich plasma injection. *PMR* 2011; 3:900–911.
39. Campanelli V, Fantini M, Faccioli N, Cangemi A, Pozzo A, Sbarbati A. Three-dimensional morphology of heel fat pad: an in vivo computed tomography study. *J Anat* 2011; 219:622–631.
40. Rome K, Webb P, Unsworth A, Haslock I. Heel pad stiffness in runners with plantar heel pain. *Clin Biomech (Bristol, Avon)* 2001; 16:901–905.
41. Prichasuk S. The heel pad in plantar heel pain. *J Bone Joint Surg Br* 1994; 76:140–142.
42. McMillan AM, Landorf KB, Gregg JM, De Luca J, Cotchett MP, Menz HB. Hyperemia in plantar fasciitis determined by power Doppler ultrasound. *J Orthop Sports Phys Ther* 2013; 43:875–880.
43. Walther M, Radke S, Kirschner S, Ettl V, Gohlke F. Power Doppler findings in plantar fasciitis. *Ultrasound Med Biol* 2004; 30:435–440.
44. Uzel M, Cetinus E, Ekerbicer HC, Karaoguz A. The influence of athletic activity on the plantar fascia in healthy young adults. *J Clin Ultrasound* 2006; 34:17–21.
45. Hirschmüller A, Frey V, Konstantinidis L, et al. Prognostic value of Achilles tendon Doppler sonography in asymptomatic runners. *Med Sci Sports Exerc* 2012; 44:199–205.