Hyperemia in Plantar Fasciitis Determined by Power Doppler Ultrasound

Plantar fasciitis is characterized by chronic inferior heel pain and point tenderness at the calcaneal origin of the plantar fascia. The condition is exacerbated by weight bearing after periods of rest and typically resolves after 12 months with conservative management. The prevalence of heel pain in the general population is estimated to range from 3.6% to 7%, and plantar fasciitis has been shown to account for 10% of musculoskeletal conditions affecting the foot and ankle.

The underlying pathology of plantar fasciitis has not been thoroughly investigated. However, a range of tissue changes at the subcalcaneal enthesis have been demonstrated in patients undergoing surgery for longstanding symptoms. The most commonly reported features are degeneration of collagen fibers, increased secretion of ground-substance proteins, focal areas of fibroblast proliferation, and increased vascularity. These findings are similar to those reported in the tendinopathy literature, in which neurovascular in-growth has been suggested to be a likely pain mechanism.

Within human musculoskeletal tissues, the close anatomical relationship between blood vessels and nerves is well known, and, as a consequence, nerves are often described as “accompanying” or “traveling with” their respective blood vessels. Accordingly, it is likely that neovascularization of connective tissue in disorders such as plantar fasciitis and tendinopathy also involves concurrent in-growth of nerve fibers, thereby increasing sensitivity to pain mediators at the site of injury. In relation to plantar fasciitis, although several histological studies have reported evidence of angiogenesis within the plantar fascia, these studies did not utilize techniques that enabled identification of nerve fibers and, therefore, did not demonstrate neural in-growth as a feature of the condition. However, concurrent in-growth of neural and vascular structures has been shown to occur with Achilles tendinopathy. Considering the close anatomical relationship between tendon and the plantar fascia (both are dense, regular connective tissue), it is likely that accompanying nerve fibers are

**RESULTS:** Hyperemia of the plantar fascia was present in 8 of 30 participants with plantar fasciitis and in 2 of 30 controls. The between-group difference for hyperemia, using a 4-point scale, was statistically significant, with participants with plantar fasciitis showing increased Doppler ultrasound signal compared to controls (Mann-Whitney U, \( P = .03 \)). However, the majority of participants with plantar fasciitis with evidence of hyperemia demonstrated very mild color changes, and only 3 were found to have moderate or marked hyperemia.

**CONCLUSION:** Mild hyperemia can occur with plantar fasciitis, but most individuals will not exhibit greater soft tissue vascularity when assessed with routine Doppler ultrasound. Clinicians treating plantar fasciitis should not consider a positive Doppler signal as essential for diagnosis of the condition but, rather, as a feature that may help to refine the treatment plan for an individual patient.

**KEY WORDS:** heel pain, imaging, neovascularization

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**STUDY DESIGN:** Cross-sectional observational study.

**OBJECTIVES:** To investigate the presence of soft tissue hyperemia in plantar fasciitis with power Doppler ultrasound.

**BACKGROUND:** Localized hyperemia is an established feature of tendinopathy, suggesting that neurovascular in-growth may contribute to tendon-associated pain in some patients. The presence of abnormal soft tissue vascularity can be assessed with Doppler ultrasound, and a positive finding can assist with targeted treatment plans. However, very little is known regarding the presence of hyperemia in plantar fasciitis and the ability of routine Doppler ultrasound to identify vascular in-growth in the plantar fascia near its proximal insertion.

**METHODS:** This observational study included 30 participants with plantar fasciitis unrelated to systemic disease and 30 age- and sex-matched controls. Ultrasound examination was performed with a 13- to 5-MHz linear transducer, and power Doppler images were assessed by 2 blinded investigators.
Doppler ultrasonography involves the processing of echoes produced by moving objects within the scanning field (eg, blood flow within a vessel). The underlying principle is that moving objects reflect the ultrasound pulse at a frequency different from that of the original transmission (known as the Doppler effect), and a frequency shift is thereby detected when the echo is received by the transducer.12 Furthermore, the direction of movement toward or away from the transducer is also determined by the nature of the frequency shift, with either a higher frequency or lower frequency detected, respectively.12 The resulting image produced demonstrates these frequency shifts by assigning colors to the corresponding display pixels, coded according to the direction and velocity of movement (ie, moving objects are represented by color images).12

In addition to color Doppler, a variation in Doppler-shift processing, known as power Doppler ultrasound (PDU), can be undertaken to improve sensitivity to slow blood flow and flow within very small or deep vessels.12 Rather than color-encoding the frequency shift according to velocity and flow direction, this process determines the power (or strength) of the Doppler shift according to the concentration of moving objects.12 In so doing, PDU is not affected by flow-direction artifacts (eg, aliasing), allowing a lower pulse-repetition frequency to be used, which improves sensitivity to slow-moving blood within small vessels.12,13 Therefore, PDU has an advantage when assessing musculoskeletal tissues for evidence of abnormal vascular perfusion.

In relation to plantar fasciitis, 1 study23 has shown a relationship between inferior heel pain and hyperemia of the plantar fascia, using PDU. In that study, moderate to marked hyperemia was observed in 8 of 20 participants with plantar fasciitis, compared to no hyperemia in 20 controls (P<.01). These results support the findings of histological studies of hyperemia in plantar fasciitis, and suggest that Doppler ultrasound assessment should be considered when imaging patients with inferior heel pain. However, that study was susceptible to bias due to methodological limitations. For example, the PDU image assessor was not blinded, and control participants were not matched for age and sex. Considering these factors, it is possible that the presence of hyperemia in the plantar fasciitis group might have been overestimated, and that between-group differences in participant characteristics (eg, there were twice as many males in the control group) might have influenced the study findings. Furthermore, a recent study4 involving PDU assessment of 9 participants with plantar fasciitis related to spondyloarthritis reported no evidence of hyperemia in those with plantar fasciitis compared to 24 controls, indicating the need for additional research in this area.

Therefore, the aim of this study was to investigate whether soft tissue hyperemia is present in plantar fasciitis, using conventional ultrasound techniques. A secondary objective was to investigate changes in plantar fascia thickness, with emphasis on clinically useful diagnostic threshold values.

**METHODS**

**ETHICAL APPROVAL FOR THE STUDY**

Protocol was granted by the La Trobe University Human Ethics Committee, and all participants gave written informed consent prior to enrollment. Ultrasound imaging was conducted at the La Trobe University Private Hospital (Bundoora, Australia) between January 2011 and February 2012.

Participants with plantar fasciitis were recruited from the local community (by newspaper advertising) and from other heel-pain projects that had recently concluded at the university. These participants were required to have a history of inferior heel pain for at least 8 weeks, with a minimum average pain severity (during the past week) of 20 mm on a 100-mm visual analog scale. Plantar fasciitis was confirmed by ultrasound assessment and considered present when the plantar fascia was 4.0 mm or greater at the calcaneal origin.16 Exclusion criteria for case participants included corticosteroid injection of the heel within the past 3 months, posterior heel pain, systemic inflammatory disease, diabetes, and a history of local surgery. Participants with bilateral heel pain had the most severely affected foot scanned. Age (±3 years) and sex-matched controls were recruited by local newspaper advertisements and from the university campus. These participants were required to have no history of inferior heel pain within 5 years preceding enrollment, and were ex-
Ultrasound examination was undertaken with participants lying prone, with their knees extended and feet resting over the edge of an examination table.16 All ultrasound images used for assessment were obtained in the sagittal plane. Plantar fascia thickness was measured at a standard location, where the fascia crosses the anterior aspect of the inferior calcaneal border (FIGURE 1).16 This measurement technique was performed with Sante DICOM Editor Version 3.1.20 software (Santesoft Ltd, Athens, Greece) and has been shown to have good intrarater reliability (95% limits of agreement: 0.5, –0.7 mm).24

Assessment of the PDU signal within the proximal plantar fascia was performed by 2 blinded podiatrists (K.B.L. and H.B.M.) with substantial experience in assessing soft tissue images of the foot and ankle. A 4-point ordinal scale was used to grade the presence of hyperemia, as originally proposed by Newman et al20 and further described by Walther et al23 specifically for plantar fasciitis, on which 1 represented normal tissue perfusion, 2 mild hyperemia, 3 moderate hyperemia, and 4 marked hyperemia with a confluent surrounding vascular blush. This grading scale was recently shown to have good correlation with a computerized method that quantified tissue vascularity by calculating the total number of color pixels in the region of interest (Spearman rho = 0.70, P < .01).24 To reach consensus on the grading of hyperemia, the 2 assessors examined PDU images together.

All ultrasound imaging was performed by experienced musculoskeletal sonographers (J.M.G. or J.D.), with a variable-frequency (13- to 5-MHz), linear-array transducer (ACUSON Antares premium edition; Siemens AG, Munich, Germany). PDU settings were standardized with a pulse-repetition frequency of 781 Hz, although 5 participants were assessed with a higher pulse-repetition frequency (977 Hz) to reduce flash artifact.25 Doppler gain was optimized by manual elevation until the first indication of color (representing background noise) began to appear at the calcaneal enthesis or proximal plantar fascia.21 The sonographers were aware of clinical history (ie, plantar fasciitis or not) during assessments.

The between-group difference for the extent of hyperemia (ordinal data) was analyzed by the Mann-Whitney U test. Correlations between the extent of hyperemia, duration of symptoms, and pain severity were analyzed with Spearman rho. The between-group difference for plantar fascia thickness was analyzed by the independent t test with 95% confidence intervals. Correlations between plantar fascia thickness, body mass index (BMI), and pain were analyzed with Pearson r. All analyses were undertaken with SPSS Version 19 software (SPSS Inc, Chicago, IL), and statistical significance was set at the conventional level of .05. Only 1 heel for each participant was scanned to meet the independence assumption of statistical analysis.18

### RESULTS

A total of 30 participants with plantar fasciitis unrelated to systemic disease and 30 age- and sex-matched controls (60 participants total) were recruited (TABLE). All participants with clinically evident plantar fasciitis had a plantar fascia thickness of 4.0 mm or greater (ie, no potential participant was excluded based on sonographic measurement of plantar fascia thickness).

Hyperemia of the plantar fascia was present in 8 of 30 participants with plantar fasciitis and in 2 of 30 control participants (TABLE). The between-group difference for hyperemia using the 4-point scale was statistically significant, with those with plantar fasciitis showing increased PDU signal compared to controls (Mann-Whitney U, P = .03). However, the majority of those with plantar fasciitis with evidence of hyperemia demonstrated very mild color changes (grade 2), and only 3 were found to have moderate or marked hyperemia (TABLE, FIGURE 2). For the plantar fasciitis group, there was no correlation between hyperemia and duration of symptoms (Spearman rho = 0.01, P =

### TABLE

<table>
<thead>
<tr>
<th>Variable</th>
<th>Participants, n</th>
<th>Control, n</th>
</tr>
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<tbody>
<tr>
<td>Age, y</td>
<td>57 ± 10</td>
<td>57 ± 10</td>
</tr>
<tr>
<td>Women, n (%)</td>
<td>15 (50)</td>
<td>15 (50)</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td>31 ± 5</td>
<td>29 ± 4</td>
</tr>
<tr>
<td>Symptom duration, mo</td>
<td>16 ± 14</td>
<td>NA</td>
</tr>
<tr>
<td>Participants with symptom duration of 6 mo or less, n (%)</td>
<td>9 (30)</td>
<td>NA</td>
</tr>
<tr>
<td>Pain on 100-mm VAS</td>
<td>55 ± 23</td>
<td>NA</td>
</tr>
<tr>
<td>Plantar fascia thickness, mm</td>
<td>6.4 ± 1.3</td>
<td>3.8 ± 0.8</td>
</tr>
<tr>
<td>Positive for hyperemia (grade 2 or above), n (%)</td>
<td>8 (27)</td>
<td>2 (7)</td>
</tr>
</tbody>
</table>

Abbreviations: NA, not applicable; PF, plantar fasciitis; VAS, visual analog scale.

*Values are mean ± SD unless otherwise indicated.
The mean between-group difference for plantar fascia thickness was statistically significant, with the value in those with plantar fasciitis being 2.7 mm greater than that for the control group (95% confidence interval: 2.1, 3.2 mm; P < .01).

For the plantar fasciitis group, there was no statistical relationship between plantar fascia thickness and pain levels (Pearson r = 0.11, P = .57). However, for the total cohort (n = 60), there was a statistically significant correlation between plantar fascia thickness and BMI (Pearson r = 0.44, P < .01).

**DISCUSSION**

The aim of this study was to investigate whether soft tissue hyperemia is present in plantar fasciitis, using conventional ultrasound techniques. Our findings show that mild hyperemia can occur with plantar fasciitis, but most individuals do not exhibit greater soft tissue vascularity when assessed with routine Doppler ultrasound. In addition, for those with plantar fasciitis, we found no statistical relationship between the presence of hyperemia and duration of symptoms or pain severity.

This study revealed a more conservative relationship between plantar fasciitis and hyperemia compared to that previously reported by Walther et al., in which 40% of participants with plantar fasciitis were graded with either moderate or marked vascularity. Moreover, a correlation between hyperemia and symptom duration, a key finding described by Walther et al., was not found in the present study, despite 30% of those with plantar fasciitis reporting a symptom history equal to or less than 6 months. These discrepancies may stem from underlying methodological differences, including the absence of age and sex matching in the study by Walther et al., variable interpretation by the assessors of the Newman grading scale, or use of blinded image assessment (as in the present study). However, we are confident that our conservative findings did not result from decreased ultrasound sensitivity, as we used a lower pulse-repetition frequency setting compared to that used by Walther et al. (781 versus 1102 Hz), which improved sensitivity to low-frequency shift.

Consistent with the findings of a systematic review investigating diagnostic imaging for plantar fasciitis, our findings show greater plantar fascia thickness in participants with plantar fasciitis compared to controls, and a strong association between plantar fascia thickness greater than 4.0 mm and heel pain. However, further exploration of our data revealed that 9 controls had plantar fascia thickness greater than 4.0 mm, and of these, 7 had a BMI of 30 kg/m² or greater. Therefore, we suggest that clinicians using threshold values to confirm plantar fasciitis consider BMI as part of their assessment, and set a higher threshold value (eg, 5.0 mm) for patients who are obese and a lower threshold value (eg, 4.0 mm) for patients who are not obese.

Regarding the pain mechanisms of plantar fasciitis, the findings of the present study support the notion that neurovascular in-growth can occur with the condition, and that increased sensitivity to pain stimulus may occur via this pathway for some patients. In relation to Achilles tendinopathy, histological studies have shown that nerve fibers are intimately associated with fine blood vessels in areas of soft tissue degeneration, indicating that hyperemia within the plantar fascia is likely to represent a corresponding increase in nerve supply. This has clinical implications regarding the management of plantar fasciitis, and suggests that some patients may respond...
well to treatments targeting neurovascular pain mechanisms, such as injection of corticosteroids or agents with direct sclerosing properties (eg, polidocanol). Furthermore, the findings of this study provide some explanation of the mechanism by which corticosteroids, which exert angiostatic effects (eg, inhibition of endothelial cell proliferation and migration), have been shown to reduce pain and tissue swelling in plantar fasciitis over a 3-month period.

In relation to image assessment, clinicians and sonographers should be aware of the normal vascular anatomy of the inferior heel and the potential artifacts that can mimic hyperemia within this region. For example, the lateral plantar artery crosses the inferior heel superficial to the plantar fascia and, therefore, could be incorrectly identified as neovascular activity. As shown in Figure 3, this vessel is particularly visible on PDU when assessing the plantar fascia in cross-section, as it traverses in a mediolateral direction from the tarsal tunnel to the lateral midfoot. The lateral plantar artery can also be seen on a longitudinal image, and should therefore be considered when assessing the region in either plane. Figure 3 also demonstrates that increased PDU signal is commonly observed at the inferior cortical surface of the calcaneus, which is an artifact caused by the difference in tissue density (and therefore echogenicity) between bone and the surrounding soft tissue. Increased signal in this area should therefore be interpreted with caution and typically does not represent true hyperemia of the soft tissue.

The findings of this study should be interpreted with several methodological limitations in mind. This study was pragmatically designed to represent normal clinical imaging environments, and therefore was unable to definitively identify the presence or absence of hyperemia in plantar fasciitis (eg, compared to histopathological assessment). Furthermore, it is possible that uncontrolled biological, environmental, and procedural factors might have influenced the appearance of microvessels in this study. For example, participants were not required to adhere to activity restrictions on the day of scanning, pressure applied to the heel during ultrasound assessment was not monitored, and smoking status was not assessed. These factors have the potential to alter perfusion within the plantar fascia, and might have influenced our observations of individual participants. Finally, while ultrasound images were assessed by blinded investigators, the sonographers were aware of the patient group, and this could have influenced the study findings.

CONCLUSION

Mild hyperemia can occur with plantar fasciitis, but most individuals will not exhibit greater soft tissue vascularity when assessed with routine Doppler ultrasound. Clinicians treating plantar fasciitis should not consider a positive Doppler signal essential for diagnosis of the condition but, rather, a feature that may help refine the treatment plan for an individual patient. Among participants with plantar fasciitis, we found no statistical relationship between the presence of hyperemia and duration of symptoms or pain severity.

KEY POINTS

FINDINGS: Mild hyperemia can occur with plantar fasciitis, but most individuals will not exhibit greater soft tissue vascularity when assessed with routine Doppler ultrasound. Among participants with plantar fasciitis, we found no statistical relationship between the presence of hyperemia and duration of symptoms or pain severity.

IMPLICATIONS: Clinicians treating plantar fasciitis should not consider a positive Doppler signal essential for diagnosis of the condition but, rather, a feature that may help refine the treatment plan for an individual patient.

CAUTION: This study involved a relatively small sample of individuals with plantar fasciitis and utilized routine ultrasound assessment techniques. Therefore, the findings may not represent the full spectrum of vascular features associated with the condition.

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REFERENCES