Plantar fasciitis is one of the most common painful foot conditions. It affects both active and sedentary adults, with a peak incidence in those between 40 and 60 years of age.\(^1\)\(^,\)\(^2\)\(^,\)\(^20\) Impaired vascularity with subsequent metabolic disturbance has been proposed as one of its causes.\(^3\)\(^,\)\(^3\)\(^1\)\(^1\) A moderate to marked increase in vascularity in the proximal plantar fascia has been observed in patients with plantar fasciitis.\(^7\)\(^,\)\(^3\)\(^1\) This increase is typical in those who have had plantar fasciitis for less than 12 months, and has been associated with greater intensity of pain.\(^3\)\(^1\) Similar vascularization has been observed in patients with Achilles,\(^2\)\(^3\)\(^6\)\(^,\) patellar,\(^9\) and rotator cuff tendinopathy.\(^8\) The intensity of pain with chronic tendinopathy has also been found to be greater in patients with tendon vascularization compared to those without.\(^8\)\(^,\)\(^1\)\(^0\)\(^,\)\(^1\)\(^2\)\(^,\)\(^1\)\(^3\) Alfredson\(^2\) proposed that vascularization in diseased tendons is one of the potential mediators of pain in tendinopathy, nerve ingrowth associated with new vessels being the cause of pain reported by patients.

Higher tendon vascularity has also been reported to be associated with greater dysfunction in patients with patellar\(^8\) and Achilles tendinopathy.\(^1\)\(^0\)\(^,\)\(^2\)\(^9\)\(^,\)\(^2\)\(^9\) Cook et al\(^9\) reported lower Victorian Institute of Sport Assessment questionnaire scores in patients with symptomatic patellar tendon with vascularization. A weak correlation between vascularization and the Victorian Institute of Sport Assessment ques-
tional scores has also been observed for those with Achilles tendinopathy. Information from these studies suggests there may also be an association between vascularization, pain, and foot dysfunction in patients with plantar fasciitis.

Patients with plantar fasciitis also typically have a thickened fascia. This change could be related to the reparative process of microtears, fiber degeneration, or edema. A fascia more than 4 mm thick is considered to be related to plantar fasciitis. Several studies have reported reductions in plantar fascia thickness after intervention, and Liang et al demonstrated an association between a thinner fascia at baseline and greater pain reduction with intervention. Therefore, the thickening of the plantar fascia is thought to have a pathological origin and to be correlated with symptoms.

The present study was designed to assess vascularity and fascia thickness using ultrasound imaging in patients with chronic plantar fasciitis, and to examine the relationship between vascularity, fascia thickness, pain, and dysfunction in patients with unilateral plantar fasciitis.

METHODS

Subjects

Thirty-eight patients with plantar fasciitis were recruited from a local hospital. The patients had been diagnosed by experienced orthopaedic surgeons based on the following clinical presentation: (1) pain and tenderness to palpation in the area of the medial tubercle of the calcaneus; (2) pain experienced in the first few steps in the morning or when getting up to walk after prolonged sitting, which initially lessened after short-distance ambulation but eventually increased after continued weight-bearing activities; and (3) pain exacerbated by walking barefoot, on the toes, or up stairs. Patients were considered eligible to participate if they fulfilled all of the following criteria: (1) between 18 and 65 years of age; (2) only 1 foot involved, so as to have the other foot as a control; (3) symptom duration greater than 3 months; (4) maximum intensity of pain in the previous week equal to or greater than 3 on an 11-point visual analog scale (VAS), where 0 represents “no pain” and 10 indicates “maximum tolerable level of pain”; and (5) no history of any systemic disease with manifestations similar to those of plantar fasciitis (including gout or seronegative arthritis). Patients with diseases that may affect lower-limb vascularity, such as diabetes mellitus, peripheral vascular disease, or foot trauma, were excluded from the study.

Twenty-one healthy subjects, with no history of heel pain in the previous 3 months, were invited to form the control group, using convenience sampling from the community. This study was approved by the Human Subject Ethics Subcommittees of the Hong Kong Polytechnic University and the Hospital Authority of Hong Kong. Written consent was obtained from each subject after a verbal explanation of the study.

Procedures

The study was conducted by an examiner in the Hong Kong Polytechnic University’s ultrasonography laboratories. The assessment protocol consisted of an ultrasound examination, patient-rated pain on an 11-point VAS, and a foot dysfunction evaluation using the Chinese version of the Foot Function Index (FFI).

A diagnostic ultrasound unit (MyLab 70 XView; Esaote SpA, Genoa, Italy), with a 4- to 13-MHz linear transducer, was preset at 13 MHz to capture images in grayscale and power Doppler mode for fascia thickness and vascularity, respectively. For the ultrasound assessment, the subject was prone, lying with the knee extended and the ankle fixed in a neutral position (Figure 1). The ultrasound examination was conducted by an examiner with a master’s degree in physical therapy. For the purpose of this study, sonographic training sessions were conducted and practiced for 6 months to enable the examiner to refine her skills. The room temperature was held at 22°C, and the subject was required to stay in the room in a sitting position for 30 minutes before the ultrasound examination.

With the ultrasound unit set to grayscale, the transducer was placed in the longitudinal plane parallel to the long axis of the proximal plantar fascia. One image, which provided the clearest view of the contour of the medial tubercle of the calcaneus and the proximal part of the plantar fascia, was captured. The thickness of the plantar fascia was measured at its insertion with the calcaneus, using on-screen calipers (Figure 2). This measurement, which we performed twice on 17 healthy subjects over a 1-week interval, was considered to have satisfactory reliability, with an intraclass correlation coefficient of 0.86 (95% confidence interval: 0.73, 0.94).

Vascularity was examined using a previously reported method. The power Doppler ultrasonography settings were standardized for high sensitivity, with low wall filtering to allow the detection of vessels with low blood flow. The pulse repetition frequency was 370 Hz, and medium persistence was used. The color gain was increased at first to a level that showed color noise and then decreased until the noise disappeared. The region of interest was delineated by a color box that was standardized at 1.5 × 1.0 cm and placed over the insertion of the plantar fascia.
The vascularity index (VI) was computed using a customized algorithm and software program (MATLAB Version 7.3.0.267R2006b; The MathWorks, Inc, Natick, MA). Details of the procedure have previously been reported by our group.7 In brief, the total number of pixels, as well as the color pixels within the region of interest, were counted by the customized software. The VI was defined as the ratio of the number of color pixels to the total number of pixels within the region of interest. The mean VI computed from 5 Doppler images demonstrated satisfactory concurrent validity assessed with the Newman scale (rho, 0.7) and good reliability (intraclass correlation coefficient = 0.89).7

Using a VAS, patients reported the worst pain felt in the previous week by drawing an arrow on a 100-mm horizontal line, with 0 representing no pain and 100 the maximum level of pain the patient could tolerate. Foot dysfunction was evaluated with the Chinese version of the FFI, a 23-item, self-administered questionnaire composed of pain, disability, and activity limitation subscales, with higher scores indicating greater dysfunction.2 The FFI has been used widely to evaluate foot function, especially in patients with plantar fasciitis.17,19,22 The Chinese version of the FFI has been validated and has shown satisfactory concurrent validity with the Medical Outcomes Study 36-Item Short-Form Health Survey (r = −0.66 to −0.44) and satisfactory reliability, with internal consistency (Cronbach α = .75–.94) and intraclass correlation coefficients ranging from 0.74 to 0.88.35

**Statistical Analysis**

Descriptive statistics were calculated for all of the measured variables. Independent t tests and chi-square tests were used to assess differences in subject characteristics between the control and patient groups. Paired t tests were used to compare the mean fascia thickness and VI between the dominant and nondominant sides of the control subjects, and to compare the patients’ affected and unaffected sides contingent on a lack of statistically significant side-to-side difference in the control group. Unpaired t tests were used to compare the affected side of the patients to the dominant side of the control group. Pearson correlation coefficients were used to examine bivariate relationships between the VI and fascia thickness in the affected feet and intensity of pain, based on VAS and FFI pain subscale scores, as well as the total score on the FFI in the patient group. Correlational analyses were first conducted on all patients with plantar fasciitis and subsequently on the subgroup of patients with a symptom duration of less than 12 months. Chronicity for subgrouping, less and more than 12 months, was set based on the findings of Walther et al,31 who reported a significant correlation between vascularity and foot pain in patients with a duration of symptoms of less than but not more than 12 months. Due to the small sample size (n = 6), we did not conduct any correlation analyses on the subgroup of patients with a symptom duration of more than 12 months. Multiple regression analysis was performed to identify whether VI and fascia thickness were associated with the outcome variables. The selection of variables for the regression analysis was based on the results of the bivariate correlation

**TABLE 1**

<table>
<thead>
<tr>
<th>Participant Characteristics</th>
<th>Patient Group (n = 38)</th>
<th>Control Group (n = 21)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y*</td>
<td>45.2 ± 9.0</td>
<td>45.1 ± 7.7</td>
<td>.99</td>
</tr>
<tr>
<td>Gender (female/male), n</td>
<td>24/14</td>
<td>9/12</td>
<td>.14</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>25.4 ± 3.2</td>
<td>23.3 ± 2.8</td>
<td>.01</td>
</tr>
<tr>
<td>Duration of symptoms, n</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-6 mo</td>
<td>14</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>6-9 mo</td>
<td>8</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>9-12 mo</td>
<td>10</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>13-24 mo</td>
<td>6</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Affected foot (dominant/nondominant), n</td>
<td>21/17</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

*Values are mean ± SD.

Abbreviation: BMI, body mass index.
analysis. Age, gender, body mass index, and duration of symptoms were entered first into the regression model. To avoid multicollinearity, any possible association between the potential independent variables (V1 and fascia thickness) was checked. The level of significance was set at $P<.05$. The statistical analysis was performed using SPSS Version 17.0 (SPSS Inc, Chicago, IL).

## RESULTS

Table 1 shows the characteristics of the 38 patients and 21 control subjects who participated in the study. The mean age and gender ratio of the 2 groups did not differ ($P>.05$). However, the patient group had a significantly greater body mass index (mean ± SD, 25.4 ± 3.2 kg/m²) than that of the control group (23.3 ± 2.8 kg/m²). Of the 38 patients, 6 had unilateral plantar fasciitis for more than 12 months.

### Fascia Thickness and Vascularity

Figure 3 shows the ultrasound images captured from the grayscale of a representative patient’s affected foot (Figure 3A), the same patient’s unaffected foot (Figure 3B), and a control subject’s dominant foot (Figure 3C), with the affected plantar fascia appearing thicker than both the healthy side and the control. Figure 4 shows images obtained from the Doppler mode of a patient’s affected (Figure 4A) and unaffected (Figure 4B) feet and of a control subject (Figure 4C). Increased vascularity was observed for the affected fascia but not on the healthy feet.

<table>
<thead>
<tr>
<th>TABLE 2</th>
<th>PLANTAR FASCIA THICKNESS AND VASCULARITY INDEX IN HEALTHY CONTROLS AND PATIENTS WITH UNILATERAL PLANTAR FASCIITIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plantar fascia thickness, mm</td>
<td>Affected/Dominant Foot*</td>
</tr>
<tr>
<td>Patients (n = 38)</td>
<td>5.0 ± 1.3</td>
</tr>
<tr>
<td>Controls (n = 21)</td>
<td>2.9 ± 0.6</td>
</tr>
<tr>
<td>Vascularity index, %</td>
<td>Affected/Dominant Foot*</td>
</tr>
<tr>
<td>Patients (n = 38)</td>
<td>2.4 ± 1.4</td>
</tr>
<tr>
<td>Controls (n = 21)</td>
<td>1.6 ± 0.4</td>
</tr>
</tbody>
</table>

*Values are mean ± SD.
cularity in the affected feet (5.0 mm and 2.4%, respectively) than in the unaffected feet (3.3 mm and 1.4%, respectively) ($P<.01$). No differences were observed between the dominant and nondominant feet in the control group (TABLE 2) ($P>.05$). Finally, when comparing the patient’s affected side to the dominant side of the control group, a thicker fascia (5.0 mm versus 2.9 mm) and greater VI (2.4% versus 1.6%) were also noted ($P<.05$).

**Ultrasound Findings and Foot Pain and Dysfunction**

TABLE 3 shows the level of association between ultrasound findings and foot pain and dysfunction. When the analysis was performed on the data of the affected side of all patients, the VI was positively associated with pain intensity reported on the VAS ($r = 0.39$, $P = .02$), FFI pain subscale score ($r = 0.59$, $P<.01$), and FFI total score ($r = 0.57$, $P<.01$). In this same group, fascia thickness was associated with FFI pain subscale and FFI total scores ($r = 0.39$ and 0.44, respectively; $P<.01$). Similar relationships were observed in the subgroup of patients with symptoms of less than 12 months in duration, with the exception of the correlation between the VI and intensity of pain as measured on the VAS, which was not significant ($P = .07$).

Multiple regression analyses were also performed for the affected side of the patient group. Based on the bivariate correlation analysis, demographics such as age, gender, body mass index, and duration of symptoms were entered first in the model. The VI was treated as the independent variable and VAS score as the dependent variable in the regression model. A similar procedure was performed to test whether the VI could be used to explain the score on the pain subscale of the FFI. Our results revealed that the VI accounted for 12.7% and 32.9% of the variance in pain intensity indicated by the VAS and the score on the FFI pain subscale, respectively ($P<.05$). Subsequently, fascia thickness and the VI were entered as independent variables and foot dysfunction as the dependent variable. In step 1, the VI accounted for 35.5% of the variance in foot dysfunction; in step 2, the VI, together with fascia thickness, accounted for 42.0% of the variance in foot dysfunction. **FIGURE 5** shows the relationship between the FFI and VI (FIGURE 5A) and between the FFI and plantar fascia thickness (FIGURE 5B) for the affected side of the 38 patients.

**DISCUSSION**

This study documented changes in fascia morphology and vascularity with ultrasound imaging in patients with chronic plantar fasciitis, and examined the relationship between these changes and pain and dysfunction in this population. The results indicate that increased vascularization at the proximal plantar fascia is associated with greater intensity of pain, and that both greater fascia thickness and vascularization are associated with increased foot dysfunction in individuals with unilateral plantar fasciitis lasting between 3 months and 2 years.

We detected greater vascularity in individuals with a history of plantar fasciitis at least 3 months in duration, with a mean VI on the affected side (2.4%) almost double that of the unaffected side (1.4%). Walther et al. were the first to investigate changes in vascularity with plantar fasciitis in vivo and found marked hyperemia in some of the symptomatic feet but not in the asymptomatic feet of those with unilateral plantar fasciitis and in the feet of healthy subjects. Plantar fasciitis is often, although not always, similar to tendinitis, and vascularization, or an occurrence of new vessels, has been previously reported in patients with Achilles' and patellar tendinopathy. However, these studies all used qualitative grading of vascularity, most often Newman grading, to categorize patients. In the current study, we quantified vascularity based on the number of color pixels detected by power Doppler within a predetermined region of interest, with reference to the calcaneus bone. With this method, the VI, based on continuous data, can be more accurate than a scale using categorical data, such as Newman grading, in detecting vascularity change. Using this method, we demonstrated significantly greater vascularity in the affected plantar fascia and also quantified the differences.

Like other connective tissues, the plantar fascia is a relatively hypovascular structure. It has been suggested that nerve ingrowth associated with new vessels in diseased tendons may be a potential mediator of pain in individuals with
tendinopathy.

Indeed, findings from the present study also provide data on the relationships between vascularization, pain, and dysfunction in patients with chronic plantar fasciitis lasting for 3 to 24 months. Only 1 previous study has reported a possible relationship between vascularity and pain, but it was in patients with plantar fasciitis of a duration less than 12 months.

Our ultrasound findings of thickened fascia in the affected side of patients with chronic plantar fasciitis concur with those of previous studies. The average thickness of the plantar fascia in healthy individuals is between 2.2 and 3.6 mm. In patients with plantar fasciitis, it ranges from 4.6 to 6.1 mm. In general, individuals with a plantar fascia thicker than 4 mm are considered to have plantar fasciitis. Our results were in agreement with the data of previous studies, with the mean fascia thickness being 2.9 mm in the controls and 5.0 mm for the affected heel of the patient group. Increased thickness could be secondary to the repair of microtears, fiber degeneration, or edema.

Our data also indicate that higher vascularity and thicker fascia were associated with greater dysfunction. A similar relationship between vascularization and dysfunction has been reported in patients with patellar and Achilles tendinopathy. Our findings extend this relationship between vascularity and dysfunction to include patients with plantar fasciitis. Results from our study indicate that about 42% of the variance in foot dysfunction can be explained by vascularization and fascia thickness. Ultrasound measurements, using both the grayscale and power Doppler modes to quantify morphology and vascularity of the plantar fascia, may provide additional information to quantify severity of the condition, guide clinical care, and make a prognosis.
Furthermore, it is theorized that reduction in pain and improvement in function in patients with tendinopathy or plantar fasciitis are linked with the normalization of vascularization. Change in vascularity may therefore be used as one of the indicators for assessing treatment efficacy. In previous studies, changes in vascularity have been shown to occur in subjects with Achilles tendinopathy following treatment with eccentric exercise\textsuperscript{23} and after sclerosing injections.\textsuperscript{4} In these studies, an initial increase in intratendinous vascularity was observed, starting on the first day after the intervention (training or injection) and persisting for 2 to 3 weeks, followed by a decline in vascularity in the successfully treated cases.\textsuperscript{3} Such observations highlight the association between vascularity and healing. Whether this regulation of vascularity also occurs in patients with plantar fasciitis is unknown. Further study is warranted to explore possible regulation of vascularity with intervention in patients with chronic plantar fasciitis, as well as the use of vascularity as an indicator for assessing treatment efficacy.

This was a cross-sectional observational study, so no cause-and-effect relationships could be established. The findings do, however, highlight possible morphological and physiological changes associated with the condition. An ultrasound unit was used to quantify the fascia thickness, and the power Doppler mode was used to quantify vascularity in the proximal plantar fascia. The operator effect is one of the drawbacks of ultrasonography.\textsuperscript{26,27} In this study, the same examiner conducted all of the ultrasound measurements and image processing to avoid interexaminer bias. This examiner had excellent knowledge of anatomy and extensive training in using ultrasound to examine the foot. The VAS scores and the self-administered FFI scores were measured or computed after the image processing had been completed. Such procedures aimed to minimize operator bias on the ultrasound findings. Another limitation is the small number of patients who had their symptoms for longer than 12 months. In our recruitment efforts, most patients who had heel pain for longer than 12 months had bilateral symptoms, and therefore did not qualify for this study. With our data, the association between vascularity and pain can only be generalized to patients with unilateral symptoms. It is also noted that the subjects recruited for this study were all Chinese. Potential morphological differences between feet across races may warrant consideration in the design of future studies.

**CONCLUSION**

This study used ultrasound imaging to provide important information about tissue morphology and vascularity changes in patients with a 3-month to 2-year history of unilateral plantar fasciitis. When compared to a control group and their unaffected side, increased vascularization and thickness near the proximal insertion of the plantar fascia were evident in the patients’ painful side. The significant association between vascularity and pain suggests a partial influence of changes in vascularity on pain perception associated with chronic plantar fasciitis.

**KEY POINTS**

**FINDINGS:** Compared to a control group and their unaffected side, increased vascularization and a thicker plantar fascia were evident on the affected side of patients with chronic plantar fasciitis. Vascularity and fascia thickness were also associated with pain and dysfunction in patients with unilateral chronic plantar fasciitis.

**IMPLICATIONS:** These results suggest that ultrasound imaging may provide objective measures of morphological and physiological changes in the plantar fascia that could potentially be used to monitor changes in the condition over time.

**CAUTION:** The results of this study are for patients with unilateral plantar fasciitis with duration of symptoms between 3 months and 2 years.

**REFERENCES**


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