Posterior tibial artery blood flow velocity is increased in patients with plantar heel pain

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Research

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Abstract

Background:

To investigate the relationship between blood flow velocities of the posterior tibial artery (PTA) and plantar heel pain (PHP) in patients with plantar fasciitis. We hypothesized that the blood flow velocities in the PTA would be significantly higher in the PHP group than in the control group.

Methods:

The participants included 23 patients (age: 49.61 ± 15.94 years; 12 men and 11 women) with PHP during gait who were diagnosed with plantar fasciitis. We also included 23 healthy participants (age: 49.13 ± 15.26 years; 10 men and 13 women) without PHP in the control group. Peak systolic velocity (PSV) of the PTA was measured using ultrasonography in all participants. PSV was measured thrice on each side, and the mean value was calculated. Differences in PSV between the groups were determined. Receiver operating characteristic curve analysis was performed to calculate the PSV cut-off value for PHP, and the cut-off value was calculated for the affected side and the difference between the right and left sides.

Results:

The PSV of the affected side in the PHP group (23.31 ± 6.86 cm/s) was significantly higher than that of the control group (16.34 ± 3.39 cm/s). The left-right side difference was also significantly higher in the PHP group (5.63 ± 4.11 cm/s) than in the control group (2.15 ± 1.38 cm/s). The cut-off value was 18.33 cm/s for the affected side and 3.35 cm/s for the difference between the right and left sides.

Conclusions:

The increase in PTA blood flow velocity in PHP patients was quantitatively demonstrated for the first time. Overall, we believe that the measurement of PSV can help with the quantitative evaluation of PHP patients.

Trial registration:

This study has been registered for clinical trials under UMIN000046875. The registration date is Oct 1st, 2021.

Background

The proportion of patients who complain of plantar heel pain (PHP) is abounding among foot disease patients, and 10% of adults contract it in their lifetime.[1] The symptoms of plantar fasciitis, including PHP, are reportedly worst in the morning and after a long period of rest.[2] However, elucidation of the cause of pain remains insufficient and clarifying the occurrence of pain is urgently required to prevent
symptom onset and shorten illness duration. Therefore, investigating the cause of the PHP crisis is critical and will provide useful information for evaluation and treatment.

Image evaluation is emphasized to understand the disease state in PHPs. In a review of imaging findings[3] of PHP patients, thickening of the plantar aponeurosis, hypoechoic and fluid accumulation in the plantar aponeurosis, increased thickness of the sub-calcaneal fat pad, and presence of calcaneal spurs were reported to be associated with PHP. However, a decrease in the thickness of the plantar aponeurosis does not significantly change the pain score.[4] Therefore, quantitative assessments that reflect the degree of pain and symptoms require further investigation.

Recently, it was clarified that blood flow velocity is related to pain in the lower back[5], shoulder joint,[6] and knee joint.[7] This was possible by the use of ultrasound (US) diagnostic imaging that can non-invasively examine the body internally. When tissue damage occurs, the body increases its blood flow rate, thereby increasing blood flow to the injured area, which promotes tissue healing. This means that by assessing blood flow velocity, healing response at the site of pain can be confirmed. In PHP research, evaluation by US is starting to be emphasized.[8] Previous studies have shown that PHP patients develop hypoechoic areas or collections of fluid around the plantar aponeurosis[9, 10] and have abnormal blood flow.[10, 11] Thus, when PHP is generated, the blood flow to the sole increases and storage of fluid component may occur. The posterior tibial artery (PTA) is the most common vessel supplying blood to the plantar area. However, the relationship between PHP and PTA blood flow velocity is not yet understood. This study aimed to determine the blood flow velocity of PTA in patients with plantar tendinitis and with PHP and to investigate the relation between them.

**Methods**

**Participants**

The participants included 23 patients with PHP during gait who were diagnosed with plantar fasciitis between September 2019 and October 2021. We also included 23 healthy participants without PHP in the control group. The data on age, height, weight, body mass index (BMI), and duration of illness were obtained from medical records. Numeric rating scale (NRS) during walking, self-administered foot evaluation questionnaire (SAFE-Q), brachial systolic blood pressure, and PTA flow velocity were measured. The SAFE-Q is a patient-based evaluation of foot symptoms in Japanese, recommended by the Japanese Society of Foot Surgery, that can be performed with an iOS app. This method of evaluation has demonstrated validity and reliability.[12] The SAFE-Q has the following five subscales: pain and pain-related, physical functioning and daily living, social functioning, shoe-related, as well as general health and well-being. This study was approved by the Institutional Review Board of the relevant institute(No. 2021-095). Written informed consent was obtained from all participants.

**Setting of measuring equipment**
The US equipment Noblus (Hitachi, Tokyo, Japan) was used for measurement. The measurements were performed according to a previously published method.[7] Brightness mode (B-mode), color Doppler, and pulse Doppler methods and a 4–8-MHz linear probe were used for measurement. One examiner who is a physical therapist with more than two years of experience in echography performed the measurements.

**Method of measuring PTA blood flow velocity**

The measurement was performed with the participant placed in the supine position on the bed, and the inside and outside malleolus of the foot juxtaposed approximately 5 cm from the bed edge. In the imaging method, PTA was identified using the power Doppler method in the short-axis image at a position where the medial malleolus was visible in the B-mode. The peak systolic velocity (PSV) of PTA was measured using the pulse Doppler method at a slant angle of 20° and an incidence angle of 60° in the blood flow direction relative to the US beam direction (Fig. 1). PSV was measured thrice, and the average value was calculated. The measurements were performed bilaterally.

To determine intra-rater reliability, one examiner (with over two years of echography test history) performed these measurements on 5 healthy adults. The examiner performed measurements with sufficient practice. The intraclass correlation coefficients (ICC) (1.3) was found to be 0.91 (minimum detectable difference (MDD) 95%: 2.23). In this study, according to the classification by Landis and Koch,[13] the intra-rater reliability of the measurement of PSV was good.

**Statistical analysis**

A sample size test using G*Power (latest ver. 3.1.9.7; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany; http://www.gpower.hhu.de/) was conducted prior to the study. The sample size was calculated to be at least 21 patients in each group when \( \alpha = 0.05 \), power = 0.8, and effect size = 0.8, to apply Student’s t-test. Shapiro-Wilk test was performed to determine the normality of the scores for patient information (age, height, weight, and BMI), PSV, NRS during walking, and SAFE-Q subscales. Student’s t-test was performed to identify group differences in patient information (age, height, weight, and BMI) and the difference between the right and left sides of PSV, and chi-squared test for independence was performed for sex. Analysis of variance with Games–Howell post hoc was performed to compare PSV between the PHP and control groups and to compare the difference in PSV within the same group. When PSV was compared between the PHP and control groups, the PSV of the right foot in the control group was used as a representative value. Receiver operating characteristic curve (ROC curve) analysis was performed to calculate the PSV cut-off value for PHP, which was calculated for the affected side and the difference between the right and left sides. Significance level was set at 5%. All statistical analyses were conducted using R4.0.2 (CRAN, freeware).

**Results**

Physical characteristic information about the PHP and control groups is presented in Table 1.
Table 1
Physical characteristics of the participants in each group

<table>
<thead>
<tr>
<th></th>
<th>PHP</th>
<th>Control</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>23</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>49.61 ± 15.94</td>
<td>49.13 ± 15.26</td>
<td>0.92</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>12 (46.15%)</td>
<td>10 (38.46%)</td>
<td>0.56</td>
</tr>
<tr>
<td>F</td>
<td>11 (42.31%)</td>
<td>13 (50%)</td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td>1.65 ± 0.08</td>
<td>1.63 ± 0.08</td>
<td>0.60</td>
</tr>
<tr>
<td>Weight</td>
<td>64.43 ± 11.71</td>
<td>58.26 ± 9.12</td>
<td>0.10</td>
</tr>
<tr>
<td>Body mass index</td>
<td>23.54 ± 3.91</td>
<td>21.9 ± 2.96</td>
<td>0.97</td>
</tr>
<tr>
<td>Blood pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mean ± standard deviation (SD)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHP: plantar heel pain</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The mean duration of disease in the PHP group was 27.13 ± 31.35 weeks.

The PSV characteristics for each group are presented in Table 2.

Table 2
Characteristics of peak systolic velocity of the posterior tibial artery in each group

<table>
<thead>
<tr>
<th></th>
<th>PHP</th>
<th>Control</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Affected side</td>
<td>Healthy side</td>
<td></td>
</tr>
<tr>
<td>PSV (cm/s)</td>
<td>23.31 ± 6.86*</td>
<td>19.39 ± 6.31</td>
<td>&lt; 0.05(ANOVA)</td>
</tr>
<tr>
<td>PSV: left-right side difference (cm/s)†</td>
<td>5.63 ± 4.11</td>
<td>2.15 ± 1.38</td>
<td>&lt; 0.05</td>
</tr>
</tbody>
</table>

mean ± standard deviation (SD), †; PSV left-right side difference is absolute value.

*; Statistically different from the control group (p < 0.05)

PHP: plantar heel pain; PSV: peak systolic velocity

The affected-side PSV in the PHP group was significantly higher than that in the control group (affected side: 23.31 ± 6.86 cm/s and control group: 16.34 ± 3.39 cm/s, p < 0.05). The left-right side difference was significantly higher in the PHP group than in the control group (PHP group: 5.63 ± 4.11 cm/s and control group: 2.15 ± 1.38 cm/s, p < 0.05).
PSV did not significantly correlate with NRS score during gait and the SAFE-Q subscales in the PHP group (Table 3).

<table>
<thead>
<tr>
<th>NRS during gait</th>
<th>R</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAFE-Q subscales</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pain and pain-related</td>
<td>0.13</td>
<td>0.56</td>
</tr>
<tr>
<td>Physical functioning and daily living</td>
<td>-0.15</td>
<td>0.51</td>
</tr>
<tr>
<td>Social functioning</td>
<td>-0.07</td>
<td>0.75</td>
</tr>
<tr>
<td>Shoe-related</td>
<td>0.19</td>
<td>0.41</td>
</tr>
<tr>
<td>General health and well-being</td>
<td>0.13</td>
<td>0.55</td>
</tr>
</tbody>
</table>

PSV: peak systolic velocity; NRS: numeric rating scale; PHP: plantar heel pain; SAFE-Q: self-administered foot evaluation questionnaire.

Similarly, there was no significant correlation between PSV and systolic blood pressure in the PHP group (p = 0.20, R = 0.34).

The unilateral cut-off value was 18.33 cm/s (area under the receiver operating characteristic curve (AUC) = 0.82, sensitivity = 77.3%, and specificity = 87.0%), and the difference between the right- and left-side cut-off values was 3.35 cm/s (AUC = 0.80, sensitivity = 69.6%, and specificity = 87.0%).

**Discussion**

Our results showed that the PSV of the affected side in PHP patients was significantly higher than that in the control group, the difference in PSV between the healthy and affected sides in the PHP patients was significantly higher than that between the two sides in controls, and that the PSV of the affected side did not correlate with NRS or SAFE-Q score. The PSV cut-off value was 18.33 cm/s for the affected side and 3.35 cm/s for the difference between the right and left sides.

Regarding image evaluations of plantar fasciitis, it is known that the plantar fasciitis thickens to ≥ 4 mm, [14–17] and the low echographic region or storage of the fluid component occurs around the plantar fasciitis in PHP cases,[9, 10, 17] and abnormal blood flow occurs.[10, 11] However, the clinical significance of the blood flow increase is unclear because quantitative evaluation is difficult. Recently, it has been shown that abnormal angiogenesis occurs at the site of injury in chronic musculoskeletal diseases,[18, 19] and the blood flow velocity in the vessels of the area increases.[6, 7] To the best of our knowledge, no research has evaluated the blood flow velocity of the PTA. Hence, the increase in blood flow velocity of the PTA in PHP patients was quantitatively shown for the first time in this study.
The plantar aponeurosis, sub-calcaneal fat pads, and tibial nerves in the heel contain vessels branching from the PTA. Therefore, microdamage to the plantar aponeurosis or sub-calcaneal fat pad results in neovascularization for tissue repair.[19] However, if the neovascularization and nerves persist even after completion of the tissue repair, chronic tendinopathy can occur.[20] As neovascularization continues, the blood flow to these vessels increases, thereby increasing blood flow velocity. Therefore, the PSV of PTA in PHP patients appears to increase.

In contrast, in this study, we found no relationship between the NRS or SAFE-Q and PSV results. It is possible that the degree of tissue damage was not related to subjective pain because the participants in this study were patients with chronic PHP. The longer the history of the disease, the more chronic and complex the pain is.[21] Since the participants in this study had a long history of the disease, it is likely that the symptom of pain did not match the blood flow in the tissue. PHP is a common overuse syndrome. For instance, in clinics, it is often observed that the symptom is exacerbated by an increase in activity, even if the symptoms had been relieved earlier. Therefore, developing treatments that combine subjective symptoms and objective opinions by quantitatively determining the repair condition of the lesion, is very desirable. In this study, the cut-off value of PSV was considered clinically useful.

**Study limitations**

This study has some limitations. First, it had a cross-sectional design, and hence it is difficult to establish how the increase in PSV is altered with pain relief in a prospective design intervention. Second, the association between PSV and imaging findings around the plantar aponeurosis was not evaluated in this study. As mentioned above, there is an association between imaging findings and pain,[14, 22] hence, it will be necessary to compare PSV with other imaging findings in future.

**Conclusions**

In this study, we measured the PSV of the PTA in patients with PHP who complained of plantar pain. The results showed that in PHP patients, the PSV values were higher on the affected side, and there was a large difference between the healthy and diseased sides. In future, it will be necessary to examine the changes in PSV over time and other factors with long-term interventions.

**Abbreviations**

BMI: body mass index

NRS: numeric rating scale

PHP: plantar heel pain

PSV: peak systolic velocity

PTA: posterior tibial artery
SAFE-Q: self-administered foot evaluation questionnaire

US: ultrasound

Declarations

Ethics approval and consent to participate: This study was approved by the Morinomiya University of Health Sciences Ethics Review Committee (Institutional Ethics Committee Approval No. 2021-095). Written informed consent was obtained from all participants.

Consent for publication: Not applicable.

Availability of data and materials: All data generated or analysed during this study are included in this published article.

Competing interests: The authors have no conflicts of interest directly relevant to the content of this article.

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Authors' contributions: FK contributed to study design and data collection, and drafted the manuscript; Sho K, and KH made critical revisions to the manuscript; Shintarou K supervised the study, contributed to analysis and interpretation of data, and made critical revisions to the manuscript. All authors read and approved the final manuscript prior to submission.

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References


**Figures**

**Figure 1**

**Peak systolic velocity (PSV) measurement of the posterior tibial artery (PTA)**

Ultrasound images. Pulse Doppler sonograms of the PTA confirmed that the blood flow had a three-phase waveform. The slant angle is adjusted manually.