Correlation between computerised findings and Newman's scaling on vascularity using power Doppler ultrasonography imaging and its predictive value in patients with plantar fasciitis

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Objectives: The purpose of this study was to correlate findings on small vessel vascularity between computerised findings and Newman's scaling using power Doppler ultrasonography (PDU) imaging and its predictive value in patients with plantar fasciitis.

Methods: PDU was performed on 44 patients (age range 30–66 years; mean age 48 years) with plantar fasciitis and 46 healthy subjects (age range 18–61 years; mean age 36 years). The vascularity was quantified using ultrasound images by a customised software program and graded by Newman's grading scale. Vascular index (VI) was calculated from the software program as the ratio of the number of colour pixels to the total number of pixels within a standardised selected area of proximal plantar fascia. The 46 healthy subjects were examined on 2 occasions 7–10 days apart, and 18 of them were assessed by 2 examiners. Statistical analyses were performed using intraclass correlation coefficient and linear regression analysis.

Results: Good correlation was found between the averaged VI ratios and Newman's qualitative scale ($\rho=0.70$; $p<0.001$). Intratester and intertester reliability were 0.89 and 0.61, respectively. Furthermore, higher VI was correlated with less reduction in pain after physiotherapeutic intervention.

Conclusions: The computerised VI not only has a high level of concordance with the Newman grading scale but is also reliable in reflecting the vascularity of proximal plantar fascia, and can predict pain reduction after intervention. This index can be used to characterise the changes in vascularity of patients with plantar fasciitis, and it may also be helpful for evaluating treatment and monitoring the progress after intervention in future studies.

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Plantar fasciitis is the most common cause of heel pain, and about 2 000 000 patients in the USA receive treatment every year because of this condition [1]. Besides mechanical loading, vascular disturbance with consequent metabolic impairment and hypoxia is thought to play an important role [2]. Indeed, fibrovascular hyperplasia and vascular proliferation were observed from microscopic specimens obtained from operative resection [3–5]. Walther et al [6] were the first group to evaluate plantar fascia vascularity non-invasively using power Doppler ultrasonography (PDU).

PDU is one of the colour flow imaging techniques that encodes the amplitude of the power spectral density of the Doppler signals [7]. This method has been used to assess soft-tissue vascularity and treatment efficacy with a variety of musculoskeletal and related problems. Changes in vascularity in synovial tissues in patients with rheumatoid arthritis [8–11], osteoarthritis [12, 13],

tendinopathy [6, 14–21] and plantar fasciitis [6] have been reported. Modulation in vascularity was observed in patients with tendinopathy after a course of intervention [14–21]. Most of these studies used the Newman's grading scale to grade the tissue vascularity [19–21]. This qualitative grading for the PDU images had high correlation with the histopathological grading of vascularity of the synovial membrane in patients with arthritis [11]. Nevertheless, Newman's grading system may not be objective and sensitive enough to differentiate subtle vascularity changes.

Recently, computerised methods were used to quantify tissue vascularity with ultrasonography. Tissue vascularity was quantified by computing a vascular index (VI), which is calculated as the ratio of the number of colour pixels to the total number of pixels within the region of interest in patients with soft-tissue problems [8, 9, 11, 17]. Note that most of these studies were conducted using colour Doppler ultrasonography. In this connection, PDU is superior to frequency-based colour Doppler ultrasonography, especially in tissues with low blood flow, such as the plantar fascia [6, 22, 23]. Ying et al [24] reported the feasibility of computerised quantification of

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vascularity in thyroid tissues with PDU. We were interested in evaluating whether the computerised quantification of vascularity could be applied on musculoskeletal tissue, such as the plantar fascia. Therefore, the purpose of the present study was to correlate the computerised VI and Newman's qualitative grading scale in quantifying plantar fascia vascularity using PDU, to evaluate the intra- and intertester reliability of the computerised quantitative method and its predictive ability of recovery in patients with plantar fasciitis. Proximal plantar fascia, which is the most commonly affected area in individuals with plantar fasciitis, according to clinical examination [25, 26] and previous B-mode ultrasonography [26–28], was chosen as the target testing area.

Methods and materials

Patient selection

44 patients (27 females, 17 males; mean age 48 years; range 30–66 years) with a clinical diagnosis (by experienced orthopaedic surgeons) of plantar fasciitis were recruited from a local hospital. The inclusion criteria were patients with planar fasciitis for more than 3 months in good health and having no history of any systemic disease with similar manifestations as plantar fasciitis, including gout and seronegative arthritis. Patients who had diseases that may affect lower limb vascularity, such as diabetes mellitus, peripheral vascular disease and foot trauma, were excluded from the study. 46 healthy subjects (34 females, 12 males; mean age 36 years; range 18–61 years) with no history of heel pain for the previous 3 months were invited to have a PDU examination on their plantar fascia twice 7–10 days apart. 18 of them were examined by 2 examiners. This study was approved by the Human Subject Ethic Subcommittees of the university and hospital. Written consent was signed from each subject after a verbal explanation of the study.

Ultrasonography

Greyscale ultrasonography and PDU were performed using a MyLab 70 X-view ultrasound unit in conjunction with a 4–13 MHz linear transducer (Esaote, Genova, Italy). In the ultrasound examination, positioning of the proximal plantar fascia was adopted as described by O'Neill [29]. The transducer was in the longitudinal plane parallel to the long axis of the plantar foot. A clear image with both the contour of the medial tubercle of the calcaneus and the proximal part of the plantar fascia, which can be seen most legibly, was acquired. Vascularity was examined using the power Doppler mode. The size of the colour box was standardised to 1.5×1 cm and was placed over the insertion of the plantar fascia (*i.e.* the middle point of the right line of the colour box is placed on the most prominent point of the calcaneus). Settings of the PDU were standardised for high sensitivity, with a low wall filter to allow detection of vessels with low blood flow and to have low colour noise. Pulsed repetition frequency (PRF) was 370 Hz, and medium persistence was used. The colour gain was first increased to a level that showed colour noise, and then

decreased until the noise disappeared [24, 30]. For each subject, five images with most abundant vascularity and consistent Doppler signals were selected and recorded. In addition, the room temperature was set to 22 °C, and subjects were required to stay in the room for 30 min before the ultrasound examination.

Image processing

The total number of pixels as well as the colour pixels within the region of interest (ROI) were counted by a customised software program (Matlab, v. 7.3.0.267R2006b, The Mathworks, Natick, MA; Figure 1). The VI was the ratio of the number of colour pixels to the total number of pixels within the ROI [24]. The ROI was defined as the total area of fascia within the 1.5×1 cm colour box. The average VI for all five images (VI_5) and for the first three images (VI_3) and the maximum VI value of the five images (VI_{max}) were computed. The PDU images were also graded by two examiners on a scale of 0–3 independently [19]. When the determined scores by the two examiners did not match, a joint evaluation was conducted to reach a consensus grade.

Extracorporeal shock wave therapy

Meanwhile, for the 44 patients with plantar fasciitis, extracorporeal shock wave therapy (ESWT) (Duolith SL1; Storz Medical, Tägerwil, Switzerland) was delivered for pain reduction. This device is a piezoelectric-type device with an energy flux density ranging from 0.08 to 1.1 mJ mm^{-2} . Patients were randomly divided to receive either three or six sessions of treatment once a week. Both groups received 1500 shocks per session, and treatment intensity was patient-guided with their most tolerable pain level. A self-administered 100-mm visual analogue scale (VAS) [31] was used to evaluate the pain level before and after treatment.

Statistical analysis

Spearman's rank correlation tests were used to assess the level of correlation between the VI and Newman's grading scale. Intraclass correlation coefficient (ICC) model 3 and model 2 were used to evaluate the intratester and intertester reliability, respectively [32]. Pearson's correlation coefficient was used to detect the relationship between baseline VIs and intensity of pain. Linear regression analysis was performed with pain reduction as a dependent variable and baseline VIs as explanatory variables. The level of significance was at $p < 0.05$.

Results

The correlation between computerised findings and Newman scaling on vascularity was found using power Doppler ultrasonography. A total of 220 images were collected from these 44 patients, with 5 images from each subject before intervention. The VI calculated from the 220 images illustrated good correlation with Newman's grading scale ($\rho = 0.70$, $p = 0.000$; Figure 2).

Figure 1. The process of power Doppler image data reduction by using the customised algorithm. (a) The region of interest (ROI; the insertional part of the fascia/tendon to bone) was extracted by outlining the boundaries (white line). (b) The ROI was initially extracted by trimming the unwanted area from the power Doppler window (box). (c) The ROI was further extracted by trimming the unwanted area from the outlined area, and the total number of pixels within the ROI was counted (left image). The colour pixels were further extracted by eliminating the greyscale pixels, and the colour pixels were counted by the algorithm.

Intratester and intertester reliability

46 healthy subjects had test-retest examinations 7–10 days apart, and 18 of them were evaluated by

Figure 2. Scatter plot of the vascular index and Newman's grading scale in patients with plantar fasciitis.

2 examiners. The intratester reliability of the two examiners showed an ICC >0.75 ($p<0.05$) only when the VI was calculated from averaging five images (Table 1). Hence, VI_5 is more reliable than VI_3 and VI_{max} . VI_5 also achieved the highest intertester reliability of 0.61. The mean difference between the first and second VI_5 was 0.15 on a range of -0.13 to 0.42 .

Predictive value of vascular index on pain reduction

44 patients with a duration of symptoms lasting from 3 months to 3 years (mean duration of symptoms: 13.11 months) received ESWT. The baseline VI was found to be related to the intensity of pain ($r=0.36$, $p=0.02$) in these 44 patients. Further analysis using linear regression analysis showed that the baseline VI was related to pain reduction after a course of intervention with ESWT only in the 19 patients with a duration of symptoms of less than 12 months. Indeed, from the regression model, the baseline VI can explain 49.2% of pain reduction after ESWT (Pearson's $r=-0.70$, $p=0.002$; Figure 3). Thus, a higher baseline VI was correlated with less reduction in pain in patients with symptoms lasting less than 1 year.

Discussion

The results from this study indicate that the VI, which reflects the vascularity of proximal plantar fascia, has a high level of concordance with Newman's grading scale. The VI also demonstrated good intratester reliability and moderate intertester reliability for the 46 healthy subjects. In addition, our study is the first to show that VI can predict recovery in patients with plantar fasciitis.

Since 1994, PDU has been suggested as a potential useful alternative to colour Doppler ultrasonography [33]. This method has become popular in assessing blood flow pattern to assist diagnosis and evaluate treatment efficacy in musculoskeletal disorders [8–11, 14, 15, 34]. An increase in vascularity in the Achilles tendon was reported in patients suffering from Achilles tendinopathy [14, 15] and in the plantar fascia in patients with plantar fasciitis with symptoms lasting for more than 6 months but less than 1 year [6]. Here, hyperaemia change was used, in addition to clinical signs [15], to categorise the patients, and also to monitor treatment effectiveness in patients with tendinopathy [14, 16–18]. Note that most of these studies used a subjective grading method proposed by Newman et al [19]. Newman's grading scale based on PDU imaging was found to be

Table 1. Intraclass correlation coefficient (ICC) analysis of the intratester and intertester reliability

Vascular index	Intratester ICC (3,1)		Intertester ICC (2,2)
	Tester 1	Tester 2	
VI_5	0.89	0.79	0.61
VI_3	0.72	0.48	0.38
VI_{max}	0.68	0.85	0.45

VI_5 , VI_3 and VI_{max} denote the vascularity index from the averaging of all five images, of the first three images and the maximum vascularity of all five images, respectively.

Figure 3. Scatter plot of the vascular index and visual analogue scale reduction in patients with a duration of symptoms of more than 3 months and less than 12 months.

correlated with histological findings in an animal study by Lee et al [34] and in a study of human subjects with arthritis by Walther et al [12]. In Lee et al's [34] arthritic rabbit knee model, synovial vascularity using contrast-enhanced PDU and histological findings were significantly correlated. In patients with osteoarthritis and rheumatoid arthritis, Walther et al [12] reported a good correlation coefficient (of 0.81) on tissue vascularity between the Newman's grading scale based on PDU images and tissue sections obtained when patients received surgery. Although the grading scale has high correlation with tissue section, it was noted that the grading scale was not able to detect subtle changes in vascularity. In view of the increasing use of PDU in diagnosing and evaluating treatment efficacy in musculoskeletal disorders, a quantified method is needed to reduce subjectivity in the grading process, and also to evaluate changes in vascularity during its recovery. Our study, based on the computation approach used for detection of vascularity on thyroid gland, reported good correlation on tissue vascularity in the plantar fascia obtained from our customised software program based on PDU images and Newman's grading scale. Direct comparison of our method with tissue section is difficult as a majority of patients (about 85%) with plantar fasciitis recovered with conservative treatment [2].

Test-retest reliability is important in any scale designed to measure change over time. Test-retest reliability reflects measurement error associated with repeated measurement by the same operator (intratester reliability) or a number of operators (intertester reliability). Findings from this study indicated good intratester (ICC=0.79–0.89 from averaged value of five images) and moderate intertester (ICC=0.66) reliability. Ultrasonography is well known for being a very operator-dependent technique [35, 36]. The intrareader reliability for the Doppler signal has been reported to vary from 0.58 to 0.96, and inter-reader reliability was 0.66, which indicated good to excellent intrareader agreement and moderate interreader reliability [35, 36]. Note that intratester reliability from both examiners in the present study had the highest test-retest reliability when the VI was computed from averaging five images. As the plantar fascia is a hypovascular area, the power Doppler signal detection is not as easy as in those big vessels in other organs. Although we

adjusted the colour gain at the level for which colour noises were not apparent, for each image required, an averaging of five images could minimise any error induced from one image, which may also help to explain why VI₅ showed higher repeatability and reproducibility than VI₃. Hence, the scanning of five images is recommended for the computation of VI. In addition, movement of the transducer during imaging may induce artefacts, which is unavoidable [37]. Such movement is more profound on an uneven surface, such as the epicondylar region. Therefore, it is essential to try to stabilise and support the wrist of the operator during imaging and to apply a light touch.

This study also explored the role that vascularity plays in the recovery of pain in patients with plantar fasciitis. An increase in vascularity was associated with greater pain intensity in patients with Achilles tendinopathy [14, 32, 38] and patellar tendinopathy [15]. In contrast, increased vascularity has also been found some time after effective treatments such as sclerosing injection [15, 16] and eccentric training [18, 38]. In patients with plantar fasciitis, Walther et al [6] first reported a moderate or severe hyperaemia in patients with less than 12 months duration of symptoms, and in these patients the grading of vascularity was related to the VAS. In line with Walther's observation, we observed an increase in vascularity in the plantar fascia in patients with a duration of symptoms of less than 12 months, and the baseline vascularity was also found to relate to the intensity of pain. Furthermore, the treatment outcome in patients with a duration of symptoms of less than 12 months was related to the baseline vascularity. In patients with higher VIs, less reduction in pain was observed after a course of either three or six sessions of ESWT. These findings demonstrated the role of vascularity in tissue recovery. Further study is needed to investigate whether baseline vascularity can be used to determine the success of intervention, as well as treatment intensity.

Conclusion

We concluded that the semi-quantitative computerised method that we used is reliable and has a high level of concordance with Newman's grading system in evaluating proximal plantar fascia vascularity. The vascularity obtained is a strong predictor for pain reduction after a course of physiotherapeutic intervention in patients with plantar fasciitis with a duration of less than 12 months. Such findings may help the therapist to determine the prognosis of their treatment outcome in patients with plantar fasciitis.

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