Efficacy of Ultrasonography at the Ankle Level for Estimation of Pedal Microcirculation

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Chronic wounds due to diabetes mellitus (DM) and/or peripheral arterial disease (PAD) often occur in the pedal region peripheral to the ankle. To predict wound healing potential of limb ulcers, skin perfusion pressure (SPP) and transcutaneous oxygen tension (TcPO$_2$) have recently become popular as the parameters that reflect skin microcirculation. On the other hand, ultrasonography for the macrocirculatory vessels has already prevailed widely as the standard vascular investigation. The skin microcirculation peripheral to the ankle probably depends on the macrocirculatory blood flow at the ankle level. Thus, this study aims to estimate whether the blood flow of the anterior tibial artery (ATA) and the posterior tibial artery, at the ankle level, reflect the values of SPP and TcPO$_2$ on the foot. The protocol enrolled 88 patients (122 limbs) with foot ulcers due to DM and/or PAD. The statistical analysis revealed that the sum of blood flow of the ATA and the PTA (posterior tibial artery), at the ankle level, significantly correlated with SPP on the foot. The findings support the availability of conventional ultrasonographic investigation to estimate microcirculation of the foot crucial for wound healing. (This article is a translation of J Jpn Coll Angiol 2014; 54: 45–50.)

Keywords: ATA + PTA flow, ultrasonography, skin perfusion pressure (SPP), transcutaneous oxygen pressure (TcPO$_2$)

Introduction

It is important to identify the circulatory condition of the lower limbs to treat foot necrosis and ulcer caused by diabetes and peripheral arterial disease (PAD), and improvement of peripheral blood flow prioritizing revascularization is the primary principle when blood flow for wound healing is insufficient.$^1$ Methods to evaluate the sufficiency of blood flow for wound healing include measurements of the skin perfusion pressure (SPP) and transcutaneous oxygen pressure (TcPO$_2$). These are simple noninvasive test methods to indirectly evaluate skin microcirculation. SPP of 40 mmHg or higher$^{2,3}$ and TcPO$_2$ of 40 mmHg$^4$ have been reported to be necessary for wound healing, and these are utilized as indices to predict healing and evaluate the therapeutic outcome of revascularization.$^{2–8}$ On the other hand, methods to evaluate the macrocirculatory system supplying blood to the microcirculatory system include vascular ultrasonography, MR angiography (MRA), and CT angiography (CTA). Vascular ultrasonography is capable of low-invasively evaluating stenosis and obstruction in real time. Although there are some problems, such as that evaluation varies due to experience and skills of examiners and screening of the whole bilateral lower limbs takes time,$^9$ it has been introduced in many institutions because it is less stressful for patients compared to MRA and CTA and very useful to evaluate blood flow in patients with lower limb ulcers.

Estimating macrocirculatory blood flow as well as microcirculation provides practical information, considering the procedure for revascularization. As blood vessels of the macrocirculatory system, we focus on the anterior (ATA) and posterior (PTA) tibial arteries at the ankle joint level,$^{10}$ and evaluate these blood vessels using ultrasonography.

Recently, techniques for revascularization distal to the ankle including below knee intervention and distal surgical bypass have been progressed.

The ATA or PTA at the ankle joint level is usually targeted as the most peripheral site for revascularization both with bypass surgery and catheter intervention. For free flap grafting, applied for large defects in plastic surgery, the recipient of microvascular Anastomosis is set to the ATA or PTA near the ankle joint. Therefore, it is significant to measure blood flow of the ATA and PTA at the ankle joint level serving as a treatment target and recipient.

Furthermore, microcirculatory hemodynamics in the foot contributing to wound healing may be dependent on the volumes of blood flow in these blood vessels at the ankle joint level as the original source. Therefore, the
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Microcirculatory condition in the foot may be evaluated by measuring blood flow in these blood vessels in the ankle joint region, even though the previous methods based on SPP and TcPO₂ are inapplicable. In this study, we analyzed the correlations between the ATA and PTA blood flow at the ankle joint level and SPP and TcPO₂ at sites peripheral to these to investigate the usefulness of the total ATA and PTA blood flow as an alternative index of skin microcirculation in the foot.

Subjects
The subjects were 88 patients with diabetic foot lesions and PAD-induced ulcers (122 feet) (96 feet of males and 26 feet of females, mean age: 66.58 ± 11.90 years old) who visited the Department of Plastic and Reconstructive Surgery, Saitama Medical University, between October 2010 and March 2011.

Methods
The subjects underwent tests in a laboratory controlled at a 25 ± 1°C room temperature after resting in a supine position for 30 min or longer. Tests were performed by the same examiner for all patients.

1. Vascular ultrasonography
   For the test device, GE Healthcare LOGIQ P6 was used. For the probe, a 7.5-MHz linear type was used. The measurement sites were the anterior and posterior tibial arteries at the ankle joint level (Fig. 1). After measuring the time averaged flow velocity (TAV) using the pulse Doppler method (Fig. 2), the color was removed, and the vascular diameters were measured at the TAV measurement sites to calculate blood flow.

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   \text{Blood flow} = (\text{vascular radius})^2 \times 3.14 \times \text{time averaged flow velocity}
   \]

   ATA and PTA blood flows were summed and presented as ATA + PTA flow.

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   \text{ATA + PTA flow} = \text{ATA blood flow} + \text{PTA blood flow}
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2. SPP
   For the test device, SensiLaseTM PAD3000 (Vasamed Inc.) was used. The measurement site was the center of the dorsum of the foot (Fig. 3A). When an ulcer was present, a region without redness was selected to avoid the influence of inflammation. A laser sensor and cuff were attached to the dorsum of the foot, and pressure was loaded on the cuff to stop skin microcirculation. The cuff pressure was then gradually reduced, and the pressure at the time of blood flow resumption was measured as SPP.

3. TcPO₂
   For the test device, TCM400 (Radiometer) was used. After cleaning and degreasing the same region as the SPP measurement site with an alcohol swab, a mounting ring was applied and then an electrode containing contact liquid was attached (Fig. 3B). Stable TcPO₂ after about 15 min was adopted.

4. Analysis
   ATA + PTA flow was calculated and its correlations with SPP and TcPO₂ measured on the dorsum of the foot were analyzed. The feet were divided into those with SPP of 40 mmHg or higher and lower than 40 mmHg as predicted.
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SPP and TcPO$_2$ were measured in 83 and 122 feet, respectively. SPP could not be measured due to pain and involuntary movement in some feet. Vascular ultrasonography and TcPO$_2$ could be measured in all feet.

1. Vascular ultrasonography
   - ATA blood flow was $29.76 \pm 26.00$ mL/min.
   - PTA blood flow was $22.45 \pm 24.06$ mL/min.
   - ATA + PTA flow was $52.22 \pm 50.04$ mL/min.

2. SPP and TcPO$_2$
   - SPP was $50.00 \pm 19.71$ mmHg.
   - TcPO$_2$ was $39.51 \pm 19.36$ mmHg.

3. Correlations of ATA + PTA flow with SPP and TcPO$_2$
   - A significant positive correlation was noted between ATA + PTA flow and SPP ($r = 0.52$, $p < 0.01$).
   - The correlation between ATA + PTA flow and TcPO$_2$ was significant ($r = 0.23$, $p < 0.01$), but the correlation coefficient was low.

4. Correlation between SPP and TcPO$_2$
   - A significant positive correlation was noted between ATA + PTA flow and SPP ($r = 0.38$, $p < 0.01$).

SPP and TcPO$_2$ were measured in 83 and 122 feet, respectively. SPP could not be measured due to pain and involuntary movement in some feet. Vascular ultrasonography and TcPO$_2$ could be measured in all feet.

**Statistical analysis**
The measurement results are presented as the mean ± standard deviation.

The correlations of ATA + PTA flow with SPP and TcPO$_2$ were analyzed using simple regression analysis, setting the significance level at less 5%. For between-group comparison, the unpaired t-test was employed, setting the significance level at less than 5%. All retrospective studies were performed after approval by Institutional Review Board (IRB) of Saitama Medical University Hospital.

**Results**

Among 122 cases the pulse Doppler Ultrasonography detected the vascular wall and lumen without flow signals inside in three cases for ATA and nine cases for PTA.

We considered the absence of flow signals had resulted from vascular obstruction rather than from vessel calcification since collateral circulation was observed around the detected vascular wall.

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(5) Comparison of ATA + PTA flow between the predicted healing and non-healing groups (Fig. 6)

ATA + PTA flow was 64.62 ± 44.71 mL/min in the predicted healing group with SPP of 40 mmHg or higher, and 38.66 ± 31.75 mL/min in the predicted non-healing group with SPP lower than 40 mmHg, showing a significant difference between the two groups (p <0.01).

Discussion

To evaluate the severity of lower limb ischemia, vascular ultrasonography, MRA, and CTA are employed as morphological diagnostic methods, in addition to the ankle brachial pressure (ABI) and toe brachial indices (TBI). Evaluation of outcomes of wound healing based on SPP and TcPO2 has recently been attracting attention.2-8 A study comparing these with SPP reported a strong correlation between SPP and TBI.3 In the Doppler blood flow waveform classification of three new patterns on vascular ultrasonography, it is concluded that the type C waveform is frequently observed in severely ischemic feet with SPP lower than 30 mmHg, and SPP is correlated with the vascular resistance index.11 Based on these findings, SPP is useful to evaluate the severity of lower limb ischemia. Conventional vascular ultrasonography is capable of noninvasively detecting stenosis and obstruction in real time, and it is frequently used for screening of stenosis- and obstruction-induced ischemia based on the blood flow waveform classification and maximum systolic blood flow rate, and to calculate the blood flow and the vascular resistance index by measuring the blood flow velocity and vascular diameter to evaluate the severity of PAD.11-13 However, generally used simple ABI paradoxically rises when the arterial wall is markedly calcified, lacking reliability, and TBI is not measurable due to defects and ulcer of the hallux, which is the usual measurement site. SPP may be unmeasurable when the body moves due to involuntary movement and pain. Actually, it could not be measured because the patient could not retain a resting position due to involuntary movement and pain in some cases in our study. TcPO2 could be measured in all patients, but it may vary due to influences of edema, keratinization, and bone protrusion at the measurement site. Moreover, the problem includes TcPO2 is not currently covered by national health insurance in Japan. In contrast, many institutions have introduced vascular ultrasonography, although there is variation due to skills of examiners as a demerit,6 because blood vessels are noninvasively extracted in real time, and blood flow can be evaluated using various indices, such as the volume of blood flow.11-14 The blood flow volume, used as an index to evaluate blood flow in our study, is inversely correlated with the vascular resistance index, and it has been reported to be useful to evaluate the treatment effect of vascular access for dialysis and discover re-stenosis early.14 On the other hand, some studies reported that it is insufficient to be used as a universal lower limb blood flow evaluation method because it is influenced by the cardiac output and heart rate.13,15 In another study, blood flow per unit area calculated by dividing the blood flow by the cross-sectional vascular area was evaluated because blood flow is readily influenced by the vascular diameter.16 In our study, the tests could be completed within a short time because of the superficial distribution of the measurement sites, the ATA and PTA at the ankle joint level, which can be easily extracted. Vascular pulsation induced no considerable measurement deviation of vascular diameter because the measurement site at the ankle was distant enough from the heart. However, all tests were performed by the same examiner while paying attention to avoid deformation caused by pressing the probe because of the superficial distribution at 10 mm from the body surface, and errors due to the vascular diameter were not investigated.

The result of this study revealed a significant correlation between ATA + PTA flow and SPP (r = 0.52), but the correlation between ATA + PTA flow and TcPO2 was weak (r = 0.23), and the correlation between TcPO2 and SPP, which also evaluates skin microcirculatory blood flow, was also weak (r = 0.38). These may have been due to large variation of measured values due to the anatomical and physiological factors of the TcPO2 measurement site and methodological influence, as described above.2

Since ATA + PTA flow and SPP were correlated, we investigated the possibility of severity classification based on ATA + PTA flow. Using SPP, which is useful to evaluate the severity, the feet were divided into two groups, with SPP of 40 mmHg or higher and lower than 40 mmHg for which wound healing was expected and not expected, respectively, and ATA + PTA flow was compared between these two groups. ATA + PTA flow was significantly higher in the group with 40 mmHg or higher SPP, suggesting that ATA + PTA flow may be used as an index to evaluate blood flow in the foot. Collateral circulation was frequently noted around the main blood vessels in patients with obstructed ATA and PTA. Formation of another route of blood supply to microcirculation in the foot was clarified by measuring the ATA and PTA, which are the most peripheral blood vessels of the macrocirculatory system. Since a blood supply route non-measurable by blood flow evaluation is present at the ankle joint level in cases of obstruction and congenital vascular defect, imaging should be concomitantly performed to evaluate collateral circulation, not easily limiting evaluation to ATA + PTA flow, and the grade of ischemia may be confirmed by investigating the overall circulatory structure.

Free flap grafting is a plastic surgical treatment, in which a vascularized flap is transplanted by vascular anastomosis.
to a tissue defect. This method may conserve the lower limb and enable a patient with difficulty to walk, but it is not indicated when the recipient's vascular diameter is thin and blood flow is low. Therefore, it is very important to evaluate the recipient's condition prior to treatment. Since the recipient of a free flap graft is normally the ATA or PTA at the ankle joint level, blood flow evaluation of this region by vascular ultrasonography is also useful to decide on the surgical indication. It was clarified that ATA + PTA flow at the ankle joint level is significantly correlated positively with SPP reflecting peripheral microcirculation. For cases with lesions localized in peripheral regions, such as obstruction, congenital ATA defect, Buerger’s disease, and blue toe syndrome, the values of ATA + PTA flow hardly reflect the microcirculation in the foot. When generally accepted examination methods such as SPP, TcPO₂, ABI and TBI are not available, blood flow measurement at the ankle joint level using vascular ultrasonography may help in the evaluation and diagnosis of peripheral skin microcirculatory hemodynamics.

Conclusion

ATA + PTA flow was calculated from the time averaged flow velocities and vascular diameters of the ATA and PTA at the ankle joint level measured using vascular ultrasonography. Its correlations with SPP- and TcPO₂-based microcirculatory blood flow of the dorsum of the foot were investigated, and a significant positive correlation with SPP was observed, suggesting that measurement of ATA + PTA flow may be used as a useful evaluation method to investigate microcirculatory hemodynamics of the foot. Since it is measured in only the main blood vessels, ATA and PTA, its concomitant use with the conventional blood flow evaluation methods may help in the treatment of lower limb ulcers. Blood flow may also be used as an index of the hemodynamics of the free flap graft recipient and evaluation of flap survival, and we are planning to investigate these.

Disclosure Statement

There is no conflict of interest regarding any of the author and co-authors.

References

1) Terashi H. Treatment of wounds. All about wounds: For all people with wounds (Supervised by Shigeru Ichioka), Kokusaido Co., Ltd., Tokyo, 2012, 128-9. (in Japanese)