Clinical reliability and utility of skin perfusion pressure measurement in ischemic limbs—Comparison with other noninvasive diagnostic methods

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Purpose: We studied whether the measurement of skin perfusion pressure (SPP) is useful for evaluating ischemic limbs and predicting wound healing.

Methods: Two hundred eleven patients (age range, 45 to 90 years; mean age, 69.6 ± 9.2 years; 170 men and 41 women), 403 limbs with arteriosclerosis obliterans, were included in this study. Half of the patients had diabetes or were receiving dialysis or both.

Results: Significant correlations were found between SPP and ankle blood pressure (ABP), SPP and toe blood pressure (TBP), and SPP and the transcutaneous oxygen pressure (tcPO2) (P < .0001, r = 0.75; P < .0001, r = 0.85; P < .0001, r = 0.62; respectively). In 94 limbs with ulcer or gangrene, wound healing was predicted by the SPP. The mean SPP (mean ± SD) in the healed-wound group (25 limbs, 48 ± 20 mm Hg) was greater than that in the unhealed-wound group (69 limbs, 23 ± 11 mm Hg) (P < .001). According to the receiver operating characteristic (ROC) curve, the cut-off value of SPP was 40 mm Hg (sensitivity, 72%; specificity, 88%). Furthermore, we studied whether the combination of SPP and another measurement could predict wound healing more accurately than could any single variable. There was a strong correlation between SPP, TBP, and the healing rate (P < .001, r = 0.69) and healing could be accurately predicted if the SPP was greater than 40 mm Hg and if the TBP was greater than 30 mm Hg.

Conclusions: Our results suggest that measurement of SPP is an objective method for assessing the severity of peripheral arterial disease or for predicting wound healing. (J Vasc Surg 2008;47:318-23.)

Among various noninvasive diagnostic methods, measurement of the skin perfusion pressure (SPP) has proven useful for assessing the severity of ischemia, 1-3 selecting the proper level of amputation, 4-7 and judging the likelihood that ischemic foot ulcers will heal. 8-10 The measurement of SPP with external compression was introduced in 1967. 11,12 Although three different techniques have been used to measure SPP, radioisotope clearance, 11-16 photoplethysmography, 16-18 and the laser Doppler, 2,16,19,20 the principle is the same. By slowly decreasing the inflation-cuff pressure at the site of measurement, the washout of the isotope, the reappearance of pulsatile flux, or the movement of red blood cells can be detected with each technique. The minimal external counter pressure on the underlying skin elicited by the pressure cuff is defined as the SPP, above which skin blood flow ceases.

In this study, we retrospectively studied whether measurements of SPP can assess the severity of limb ischemia and predict wound healing of the ischemic limb more accurately than can other noninvasive examinations, such as ankle blood pressure (ABP), the toe blood pressure (TBP), and the transcutaneous oxygen pressure (tcPO2).

PATIENTS AND METHODS

The subjects were 211 patients (403 limbs), who were referred to the vascular laboratory in the Department of Vascular Surgery at Aichi Medical University Hospital for evaluation of arterial insufficiency due to arteriosclerosis obliterans from April 2002 through June 2006. The demographic characteristics and atherosclerotic risk factors of patients are shown in Table I. The clinical characteristics of the 403 examined limbs are shown in Table II. The SPP was measured by placing a laser Doppler probe beneath a 5.8-cm-wide blood pressure cuff at the dorsum of the foot. The ABP was measured with Doppler technique using a 12-cm-wide standard pneumatic cuff. We excluded lower extremities with an ABP index (ABPI) ≥ 1.15 in patients who had diabetes mellitus or were receiving hemodialysis or both. The TBP of the first toe was measured with photoplethysmography using a 2-cm-wide digital pneumatic cuff. The tcPO2 were measured by placing the sensor at the dorsum of the foot. Every noninvasive test was performed by two qualified
vascular technologists with the subject in the supine position 30 minutes after bed rest in an environment at temperature of 25°C.

Twenty-six limbs with ulcer or gangrene required major amputations soon after admission to our hospital because of extensive ischemia. The course of wound healing was assessed in 94 limbs with ulcer or gangrene. Wound healing was followed up for at least 3 months. The endpoints of treatment were whether the wound itself or the stump of the minor amputation healed or failed to heal and were judged retrospectively.

The values are expressed as means ± standard deviation. The correlations between the SPP and other variables obtained with noninvasive methods were analyzed with Pearson’s test. Differences in the result of SPP and other examinations between healed and unhealed ulcers were analyzed with the Mann-Whitney test. The cut-off values were provided by receiver operating characteristic (ROC) curves. Whether SPP can independently predict wound healing were analyzed with the multivariable logistical regression. SPP can independently predict wound healing. Such factors as artery calcification, toe amputation, diabetes mellitus, and hemodialysis did not influence the prediction of wound healing.

Seventy-three limbs with ulcer or gangrene were assessed with the ABP. The wounds healed in 19 limbs but failed to heal in 54 limbs. The ABP in the healed-wound group (106 ± 44 mm Hg) was significantly greater than that in the unhealed-wound group (63 ± 38 mm Hg) (P = .001; Table III). According to an ROC curve (Fig 2), we chose a threshold of 80 mm Hg for ABP. The rate of local healing was only 11% if the ABP was less than 80 mm Hg but was 45% if the ABP was greater than 80 mm Hg (sensitivity, 74%; specificity, 70%).

Sixty-four limbs with ulcer or gangrene were assessed with the TBP. The wounds healed in 16 limbs but failed to heal in 48 limbs. The TBP in the healed-wound group (37 ± 20 mm Hg) was significantly greater than that in the unhealed-wound group (14 ± 13 mm Hg) (P < .001; Table III). According to an ROC curve (Fig 2), we chose a threshold of 30 mm Hg for TBP. The rate of local healing was only 12% if the TBP was less than 30 mm Hg but was 67% if the TBP was greater than 30 mm Hg (sensitivity, 63%; specificity, 90%).

Ninety-three limbs with ulcer or gangrene were assessed with the tcPO2. The wounds healed in 25 limbs but failed to heal in 68 limbs. The tcPO2 was significantly greater in the healed-wound group (31 ± 17 mm Hg) than in the unhealed-wound group (10 ± 15 mm Hg) (P < .001; Table III). According to an ROC curve (Fig 2), we chose a threshold of 30 mm Hg for tcPO2. The rate of local healing was only 14% if the tcPO2 value was less than 30 mm Hg but was 63% if the tcPO2 was greater than 30 mm Hg (sensitivity, 60%; specificity, 87%).

For predicting wound healing using ROC analysis (Fig 2), the measurement of SPP was more reliable than the measurement of ABP, TBP, or tcPO2. Furthermore, we studied whether the combination of SPP and another measurement could predict wound healing more accurately than could any single variable. The relationship

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**Table I. Characteristics of the 211 patients**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Count (Percentage)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td>211</td>
</tr>
<tr>
<td>Men: women</td>
<td>170 (81%): 41 (19%)</td>
</tr>
<tr>
<td>Age (mean ± SD), years</td>
<td>69.6 ± 9.2</td>
</tr>
<tr>
<td>Smoking</td>
<td>155 (73%)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>144 (68%)</td>
</tr>
<tr>
<td>Hypercholesterolemia</td>
<td>65 (31%)</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>105 (50%)</td>
</tr>
<tr>
<td>Hemodialysis</td>
<td>44 (21%)</td>
</tr>
<tr>
<td>Ischemic heart disease</td>
<td>59 (28%)</td>
</tr>
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</table>

**Table II. Characteristics of the 403 examined limbs**

<table>
<thead>
<tr>
<th>Rutherford’s classification</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 0</td>
<td>186</td>
</tr>
<tr>
<td>Grade I</td>
<td>100</td>
</tr>
<tr>
<td>Grade II</td>
<td>23</td>
</tr>
<tr>
<td>Grade III</td>
<td>94</td>
</tr>
<tr>
<td>No diabetes &amp; no dialysis</td>
<td>183</td>
</tr>
<tr>
<td>Diabetes &amp; no dialysis</td>
<td>143</td>
</tr>
<tr>
<td>No diabetes &amp; dialysis</td>
<td>24</td>
</tr>
<tr>
<td>Diabetes &amp; dialysis</td>
<td>53</td>
</tr>
</tbody>
</table>

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Linear correlations were found between SPP and ABP (P < .0001, r = 0.748; Fig 1, A), TBP (P < .0001, r = 0.853; Fig 1, B), and tcPO2 (P < .0001, r = 0.620; Fig 1, C). The SPP was a reliable variable because SPP correlated with ABP, TBP, and tcPO2.

Ninety-four limbs with ulcer or gangrene were assessed with the SPP. The wounds healed in 25 limbs but failed to heal in 69 limbs. The SPP in the healed-wound group (48 ± 21 mm Hg) was greater than that in the unhealed-wound group (23 ± 11 mm Hg) (P < .001; Table III). According to an ROC curve (Fig 2), we chose a threshold of 40 mm Hg for skin perfusion pressure (SPP). The rate of local wound healing was only 10% if the SPP was less than 40 mm Hg but was 69% if the SPP was greater than 40 mm Hg (sensitivity, 72%; specificity, 88%). The rate of wound healing was 100% with an SPP greater than 50 mm Hg but was minimal with an SPP less than 20 mm Hg. According to the multivariable logistical regression, SPP can independently predict wound healing. Such factors as artery calcification, toe amputation, diabetes mellitus, and hemodialysis did not influence the prediction of wound healing.

Seventy-three limbs with ulcer or gangrene were assessed with the ABP. The wounds healed in 19 limbs but failed to heal in 54 limbs. The ABP in the healed-wound group (106 ± 44 mm Hg) was significantly greater than that in the unhealed-wound group (63 ± 38 mm Hg) (P = .001; Table III). According to an ROC curve (Fig 2), we chose a threshold of 80 mm Hg for ABP. The rate of local healing was only 11% if the ABP was less than 80 mm Hg but was 45% if the ABP was greater than 80 mm Hg (sensitivity, 74%; specificity, 70%).

Sixty-four limbs with ulcer or gangrene were assessed with the TBP. The wounds healed in 16 limbs but failed to heal in 48 limbs. The TBP in the healed-wound group (37 ± 20 mm Hg) was significantly greater than that in the unhealed-wound group (14 ± 13 mm Hg) (P < .001; Table III). According to an ROC curve (Fig 2), we chose a threshold of 30 mm Hg for TBP. The rate of local healing was only 12% if the TBP was less than 30 mm Hg but was 67% if the TBP was greater than 30 mm Hg (sensitivity, 63%; specificity, 90%).

Ninety-three limbs with ulcer or gangrene were assessed with the tcPO2. The wounds healed in 25 limbs but failed to heal in 68 limbs. The tcPO2 was significantly greater in the healed-wound group (31 ± 17 mm Hg) than in the unhealed-wound group (10 ± 15 mm Hg) (P < .001; Table III). According to an ROC curve (Fig 2), we chose a threshold of 30 mm Hg for tcPO2. The rate of local healing was only 14% if the tcPO2 value was less than 30 mm Hg but was 63% if the tcPO2 was greater than 30 mm Hg (sensitivity, 60%; specificity, 87%).

For predicting wound healing using ROC analysis (Fig 2), the measurement of SPP was more reliable than the measurement of ABP, TBP, or tcPO2. Furthermore, we studied whether the combination of SPP and another measurement could predict wound healing more accurately than could any single variable. The relationship
between SPP, ABP, and healing is shown in Fig 3, A. Both SPP and ABP could be measured in 73 limbs. There was a significant correlation between the two variables ($P < .001$, $r = 0.646$). However, many limbs with unhealing wounds had high ABP values. Therefore, we believe that the use of SPP and ABP to predict wound healing was not clinically useful.

The relationship between SPP, TBP, and healing is shown in Fig 3, B. Both SPP and TBP could be measured in 64 limbs. There was a strong correlation between the two variables ($P < .001$, $r = 0.690$). Healing could be more accurately predicted if the SPP was greater than 40 mm Hg and if the TBP was greater than 30 mm Hg. The relationship between SPP, tcPO2, and healing is shown in Fig 3, C. Both SPP and tcPO2 could be measured in 93 limbs. There was a significant correlation between the two parameters variables ($P < .001$, $r = 0.455$). However, many limbs with unhealing wounds had high tcPO2 values. Therefore, we believe that the use of SPP and tcPO2 to predict wound

Table III. Results of various noninvasive methods in limbs with critical ischemia

<table>
<thead>
<tr>
<th>Diagnostic method (number of limbs)</th>
<th>Healed-wound</th>
<th>Unhealed-wound</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPP (n = 94)</td>
<td>48.2 ± 20.7</td>
<td>22.5 ± 11.1</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>ABP (n = 73)</td>
<td>106.2 ± 43.8</td>
<td>63.4 ± 37.7</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>TBP (n = 64)</td>
<td>37.3 ± 20.4</td>
<td>14.1 ± 12.6</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>tcPO2 (n = 93)</td>
<td>30.6 ± 17.3</td>
<td>10.0 ± 15.2</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

*SPP, skin perfusion pressure; ABP, ankle blood pressure; TBP, toe blood pressure; tcPO2, transcutaneous oxygen pressure.

*Smean ± standard deviation, mm Hg.

Fig 2. ROC curve for the threshold of each examination. Cut-off values: ankle blood pressure (ABP), 80 mm Hg; toe blood pressure (TBP), 30 mm Hg; SPP, 40 mm Hg; and transcutaneous oxygen pressure (tcPO2), 30 mm Hg. The measurement of SPP was more reliable than the measurements of ABP, TBP, and tcPO2.
healing was not clinically useful. In conclusion, SPP was able to predict wound healing more accurately when combined with TBP.

DISCUSSION

Noninvasive measurements of ABP, TBP, and tcPO2 have been widely accepted in the assessment of the severity of peripheral arterial disease, including the evaluation of critical limb ischemia. Measurements of ABP may fail to reflect the severity of peripheral ischemia if the underlying vessels are calcified in patients who have diabetes mellitus or are receiving hemodialysis or if there is an extensive distal arterial lesion below the ankle.21-24 Many reports have suggested reliable cut-off values of ABPI in patients who have diabetes or are receiving a dialysis or both: ABPI < 1.15, < 1.30, or < 1.40.24-26 In the present study, about half of the patients had diabetes or were receiving dialysis. We excluded 52 limbs with an ABPI < 1.15, all of which were in patients who had diabetes or were receiving dialysis or both.

In contrast to ABP, measurements of TBP provide accurate information even in noncompressible vessels, and false positive results are rare.24,27 The main limitation is that measuring the TBP may be impossible in the first toe owing to ulceration or tissue loss.24-26 In the present study, the TBP could not be measured in 36 limbs. Measurements of tcPO2 have been also used to assess the severity of lower-limb ischemia. However, measurements of tcPO2 are unreliable because they are influenced by many physiological, methodological, and technical factors. The tcPO2 could not be measured in 23 limbs because of intolerable pain during the examination in the supine position.

It is noteworthy that measurements of the SPP had no such limitations. The results of multivariable logistical regression suggest that SPP is useful for predicting wound healing in limbs in which neither ABP nor TBP can be measured.

The present study shows that the regression coefficient between TBP and SPP was greater than that between ABP and SPP or that between tcPO2 and SPP. Similar relations between measurements of SPP and TBP have been suggested by several authors.22,23,28 In these reports, the SPP correlated especially well with TBP in patients with or without diabetes and could be substituted for TBP in patients in whom TBP could not be measured.8,23

A variety of trials to determine the cut-off value of SPP, which may predict the healing ability of the ischemic wound, have been performed. Reported cut-off values of SPP are ≥ 30 mm Hg5,6,19 and ≥ 40 mm Hg.8,29 The results of our study did not demonstrate the high sensitivity or specificity found in some previous studies.5,8,29 In daily practice, however, we have found that cut-off values are not reliable in many patients. Although a trial to determine the statistically calculated
cut-off value would seem to be meaningful, wound healing does not always depend on only a focal circulatory disorder but may also depend on the severity of infection and the size and depth of the wound.

As shown in Fig 3, B, there was a strong correlation between SPP and TBP (P < .001, r = 0.690). The healing could be accurately predicted if the SPP was greater than 40 mm Hg and if the TBP was greater than 30 mm Hg. All limbs with greater values deserve a trial of conservative treatment or minor amputation. Although the clinical usefulness of SPP has not yet gained widespread acceptance,26,31,32 our results suggest that the measurement of SPP is an objective method for assessing the severity of peripheral arterial disease or for predicting wound healing.

AUTHOR CONTRIBUTIONS

Conception and design: TO, TY
Data collection: TY
Writing the article: TO, TY
Critical revision of the article: TO
Final approval of the article: TO
Statistical analysis: TY
Obtained funding: Not applicable
Overall responsibility: TO

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REFERENCES


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History  Lifeline Research Meeting Abstracts
Reporting Standards  Reviews
Technical Notes