

Skin perfusion pressure of the foot is a good substitute for toe pressure in the assessment of limb ischemia

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Purpose: Noninvasive measurements of limb systolic pressures are used routinely in the assessment of the severity of peripheral arterial disease, including the evaluation for critical limb ischemia. However, ankle pressures cannot be measured reliably in patients with medial calcification, which is especially common among patients with diabetes. Skin lesions on the toes or previous digital amputations may preclude the measurement of toe pressures. Measurements of skin perfusion pressure (SPP) are not subject to such limitations and were shown to be useful in the assessment of the severity of peripheral arterial disease. Because toe pressure is often used in the evaluation of severity of arterial disease and in the assessment for critical ischemia, we undertook to study whether there is a sufficient correlation between toe pressure and foot SPP that would allow the use of SPP measurements when toe pressures cannot be measured.

Methods: Measurements were carried out in 85 limbs of 71 patients referred to the vascular laboratory for evaluation for peripheral arterial disease. Diabetes mellitus was present in 43 patients. Each patient had foot SPP and toe pressure measurements. Toe pressures measured with photoplethysmography were correlated with foot SPP measured with laser Doppler scanning.

Results: There was a strong linear correlation between SPP and toe pressure ($r = 0.87$; $P < .01$). Also, significant correlation was found in both the patients with diabetes and the patients without diabetes ($r = 0.85$ and 0.93 , respectively; $P < .01$ in both cases).

Conclusions: We concluded that SPP measured in the foot correlates well with toe pressure and can be substituted for toe pressure measurement in patients in whom toe pressures cannot be measured. (J Vasc Surg 2000;32:32-6.)

Noninvasive measurements of limb systolic pressures have been applied successfully to the diagnosis and follow-up of individual patients with peripheral arterial disease, to the study of the natural history of the disease, and to the evaluation of results of surgery and of other forms of therapy.¹⁻³ Both ankle

and toe systolic pressures correlate well with the severity of the symptoms and with the angiographic findings.³⁻⁶ Ankle and toe pressures are used as standards for classification of the severity of the arterial disease and in the assessment for the presence of critical limb ischemia.^{7,8}

However, arterial rigidity associated with medial calcification may interfere with measurements of ankle pressures. In some cases, it may be impossible to stop the flow even with cuff pressure of 300 mm Hg, or the pressures may be falsely exaggerated. These phenomena were found in 17% to 24% of diabetic limbs and have also been reported in patients undergoing renal dialysis after renal transplantation and in other elderly patients.^{3,9,10} Also, measurements of pressure at the ankle will not detect isolated obstruction in one or even two of the three branches of the popliteal artery between the knee and the ankle or the obstruction in the more distal vessels in the foot itself.^{3,4} In contrast, toe systolic pressures reflect the effect of the overall obstruction

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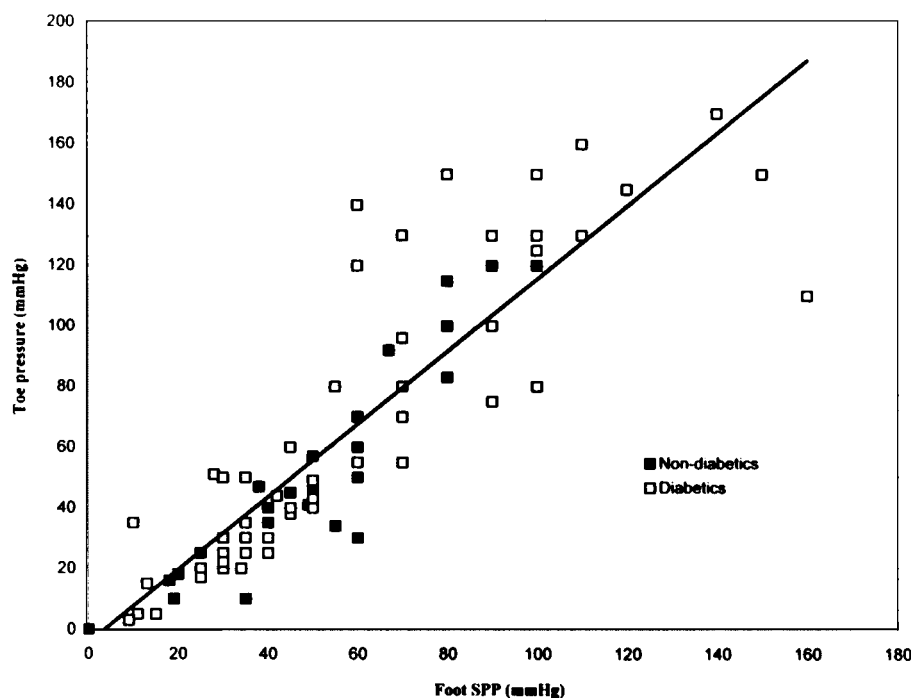
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The relationship of toe pressure to SPP of the foot. ($r = 0.87$, $N = 85$ limbs, toe pressure = 1.20 [SPP] -4.26).

in the arterial tree proximal to the measured digits and are not thought to be affected by arterial calcification.^{2,3,9} However, the presence of skin ulcers, gangrene, or previous digital amputation may preclude measurements of toe pressures. This has been reported in 5% of 346 limbs in 309 patients with skin lesions who were referred consecutively to the vascular laboratory, including 56% with diabetes (S. A. Carter and R. B. Tate, unpublished data, 1999), and in 27% of 159 patients with diabetes who had foot lesions.¹⁰

Measurement of skin perfusion pressure (SPP) is a noninvasive test that has been shown to be useful in the assessment of peripheral arterial disease, especially in the determination of the optimal level for amputation, and in the assessment of critical ischemia.¹¹⁻¹⁵ Similar to the toe pressure, SPP reflects the overall status of the more proximal arterial system and is not affected by arterial wall calcification. However, SPP can be measured in the limbs when skin lesions on the toe or digital amputation precludes measurement of the toe pressure. This study was undertaken to determine whether SPP measured in the foot was comparable to the toe pressure and could be used in the assessment of limbs for the severity of the obstruction and for crit-

ical ischemia, especially in cases in which the toe and ankle pressures cannot be determined.

METHODS

Seventy-one patients referred to the vascular laboratory for evaluation of peripheral arterial disease were studied from June 1997 to February 1998. There were 53 men and 18 women. Their age ranged from 33 to 89 years, with a mean age of 68 years. Forty-three patients (54 limbs) had diabetes. Measurements were carried out in 85 limbs with the patient in the supine position. Toe pressures were measured with photoplethysmography.¹⁶⁻¹⁸ A pneumatic cuff was wrapped around the proximal phalanx of the great toe, and a photoelectric probe was placed distal to the cuff. The pneumatic cuff was inflated to a suprasystolic pressure and then deflated until the tracing showed deflection. The pressure at which the deflection in the tracing occurred was taken to be the toe systolic pressure.

The SPP was measured in the patient while in the supine position at room temperature with a laser Doppler probe enclosed within the bladder of the cuff wrapped around the patient's forefoot.¹⁵ The pneumatic cuff was then inflated to a suprasystolic pressure. At this pressure, the laser Doppler flux was

less than 0.1 volume percent. The cuff was deflated stepwise in decrements of 10 mm Hg until 50 mm Hg and then 5 mm Hg decrements below 50 mm Hg. Pressure was held for 15 seconds at each pressure interval. Deflation was continued until two consecutive increases in laser Doppler scan flux were noted. The first increase in laser Doppler output represents the initiation of blood flow into the regional microcirculation and was taken to be the foot SPP. The technique of SPP measurement has been described previously^{14,15} and illustrated in detail.^{19,20} The relationship of the toe pressure to foot SPP was assessed by using linear regression and Pearson correlation coefficients.

RESULTS

The Figure shows the relationship of the SPP to toe systolic pressure in all limbs. The correlation coefficient was 0.873 ($P < .01$). Similarly, high correlation coefficients were found for the diabetic and nondiabetic limbs (0.854 and 0.934, respectively; both $P < .01$). In 72 (85%) of the 85 limbs, toe pressure and SPP were both 30 mm Hg or less and more than 30 mm Hg.

DISCUSSION

Our results show that SPP correlates closely with the toe systolic pressure in the limbs of patients with diabetes and patients without diabetes. Good correlation between toe pressure and SPP was shown previously with the use of the radioisotope clearance technique to measure SPP.²¹ The SPP measured with the laser Doppler probe correlates well with measurements with the use of the radioisotope technique, but it is less time-consuming. Foot SPP can be measured in less than 5 minutes per limb with the laser Doppler method.

Ankle pressure 50 mm Hg or less and toe pressure 30 mm Hg or less have been proposed as criteria for the determination of critical limb ischemia.⁸ Although the validity of these criteria has been challenged,^{22,23} pressure measurements are well standardized and at this time remain the best method to quantitate the severity of arterial disease and estimate the likelihood of critical ischemia.^{7,8}

Because ankle pressures cannot be measured in a significant proportion of patients with diabetes or renal failure and toe pressure cannot be measured in patients with skin lesions on the toes or who had previous digital amputations, measurements of SPP are a convenient method that can be applied in such patients and used as a substitute for toe pressure. Furthermore, SPP can be measured on the foot in the region where skin ulcers are often located rather

than proximally at the ankle or distally at the toe. This might provide a better criterion for the healing or nonhealing of such lesions. Whether or not that is the case, outcome studies in which SPP and toe pressure are compared will be required.

It is likely that the presence or absence of critical ischemia depends not only on the local systolic pressure but also on the events in the microcirculation resulting from ischemia and the adequacy of perfusion of the tissues in limbs with severe arterial disease.⁸ It has been suggested that measurements related to tissue perfusion such as transcutaneous oxygen pressure and digital pulsation may improve assessment for critical ischemia when combined with pressure measurements.^{7,18,24,25} Because SPP reflects perfusion pressure in smaller vessels, it might provide a better index of the presence or absence of critical ischemia than ankle or toe pressures. Prospective outcome studies are needed to assess this possibility.

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DISCUSSION

Dr Felix Tsai. I will answer the first two questions together. Our purpose of the study was not to determine any cutoff point in using skin perfusion pressure as an indicator for wound healing. However, I did reference our earlier studies, and I shall give you some numbers just so you know what to use.

In a previous study we had a total of 61 patients, half of whom required major revascularization, half of whom were given local wound healing. Thirty-one of the 32 patients requiring major revascularization had skin perfusion pressures less than 30 mm Hg. Of the 29 patients who underwent local wound healing, 75% of the patients who healed had skin perfusion pressures greater than 30 mm Hg.

Eighty-four percent of the patients who failed to heal with local therapy had skin perfusion pressures less than 30 mm Hg. We tend to use 30 mm Hg as our cutoff in terms of healing, but this study was mainly used to compare toe pressures and skin perfusion pressure.

In regard to the third question Dr Ballard asked, if we compared it with other testing modalities such as TCP02 or digital pulsatility, we do not have great experience with TCP02 at our institution, so we chose not to compare it at this time. We hope to have another prospective study soon comparing different testing modalities in a specifically defined patient population to determine the correlation between, for instance, toe pressure, TCP02, and skin perfusion pressure.

For the fourth question, how easy is it to learn this technique and how well do the patients tolerate the technique, when we first started doing this study I had to learn how to do this technique from the vascular technologists, and I got to be the guinea pig for several tests.

It takes about 5 minutes to learn. It is a handheld con-

trol to release the pressure device. So that takes a little practice, but it is fairly easy to learn and fairly well tolerated for the most part by patients.

Dr Baker. Have you studied variability in the measurements that might result from differences in skin temperature or cigarette smoking?

Dr Tsai. There have been previous studies documenting skin perfusion pressure reproducibility given the fact of things like temperature, whether the patient has ingested quantities of caffeine or alcohol or had been smoking, and how well these correlate.

You are right. There is some change with skin perfusion pressure. It is not an exact test; however, reproducibility appears to be pretty good in our institution.

Dr DeLaira. When this device first came out, I used it in a study of women who were undergoing radiation for breast cancer to see if we could follow what changes in skin occurred using the laser Doppler. We found there was a strong influence between the results we had and the patient's skin color. For fairer skinned individuals, the device worked very well. For darker skinned individuals, the device did not work at all.

Did you see any of that and does that influence your results?

Dr Tsai. Unfortunately, I am not able to tell you regarding the skin color of our patients. At our home institution, for the most part, our patients are fair skinned, and so we do not have a lot of variability in our skin perfusion pressure.

Dr Andros. You told us about a technique that is proxy for measurement of toe pressures. I am proud of our society in that two of the people that first described toe pressures as an index foot perfusion are members of this society, Vic Bernhard and Sergio Salles-Cunha.

Have you measured all five toes? We have measured all five toes, and in diabetics we find quite a variation because of changes in intrapedal circulation. We also studied ankle/arm indices in diabetics and found that in those patients that are compressible, there is a major variation among the dorsal pedis, posterior tibial, and peroneal arteries. So there is a variation in that. Did you measure only the first toe?

My final question is, if a patient has no toes, what is the indication for measuring perfusion of the skin of the foot?

Dr Tsai. Excellent questions. No, we did not measure all five toes. We only measured the great toe in our patients.

In terms of comments about the ABIs in diabetics, Dr Carter has some unpublished data that show that he found over a quarter of his patients with diabetes had noncompressible vessels. So we did not measure ABIs in those patients.

In terms of patients with no toes, they still get skin lesions of the forefoot, of the insole, and on the sole of the foot. The indication is to determine if critical ischemia is present and if they will need some sort of revascularization technique or amputation. We think that skin perfusion pressure may be helpful.

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