Use of a peripheral perfusion index derived from the pulse oximetry signal as a noninvasive indicator of perfusion

Alexandre Pinto Lima, MD; Peter Beelen, RN; Jan Bakker, MD, PhD

Objective: Peripheral perfusion in critically ill patients frequently is assessed by use of clinical signs. Recently, the pulse oximetry signal has been suggested to reflect changes in peripheral perfusion. A peripheral perfusion index based on analysis of the pulse oximetry signal has been implemented in monitoring systems as an index of peripheral perfusion. No data on the variation of this index in the normal population are available, and clinical application of this variable in critically ill patients has not been reported. We therefore studied the variation of the peripheral perfusion index in healthy adults and related it to the central-to-toe temperature difference and capillary refill time in critically ill patients after changes in clinical signs of peripheral perfusion.

Design: Prospective study.

Setting: University-affiliated teaching hospital.

Patients: One hundred eight healthy adult volunteers and 37 adult critically ill patients.

Interventions: None.

Measurements and Main Results: Capillary refill time, peripheral perfusion index, and arterial oxygen saturation were measured in healthy adults (group 1). Capillary refill time, peripheral perfusion index, arterial oxygen saturation, central-to-toe temperature difference, and hemodynamic variables were measured in critically ill patients (group 2) during different peripheral perfusion profiles. Poor peripheral perfusion was defined as a capillary refill time >2 secs and central-to-toe temperature difference ≥°C. Peripheral perfusion index and arterial oxygen saturation were measured by using the Philips Medical Systems Viridia/56S monitor. In group 1, measurements were made before and after a meal. In group 2, two measurements were made, with the second measurement taken when the peripheral perfusion profile had changed. A total of 216 measurements were carried out in group 1. The distribution of the peripheral perfusion index was skewed and values ranged from 0.3 to 10.0, median 1.4 (inner quartile range, 0.7–3.0). Seventy-four measurements were carried out in group 2. A significant correlation between the peripheral perfusion index and the core-to-toe temperature difference was found (R² = .52; p < .001). A cutoff peripheral perfusion index value of 1.4 (calculated by constructing a receiver operating characteristic curve) best reflected the presence of poor peripheral perfusion in critically ill patients. Changes in peripheral perfusion index and changes in core-to-toe temperature difference correlated significantly (R² = .52, p < .001).

Conclusions: The peripheral perfusion index distribution in the normal population is highly skewed. Changes in the peripheral perfusion index reflect changes in the core-to-toe temperature difference. Therefore, peripheral perfusion index measurements can be used to monitor peripheral perfusion in critically ill patients. (Crit Care Med 2002; 30:1210–1213)

Key Words: skin temperature; peripheral perfusion; shock; hemodynamics; monitoring; central temperature

Early recognition of impaired organ perfusion is important to avoid tissue hypoxia that ultimately could lead to organ failure. During circulatory shock, skin blood flow decreases to preserve vital organ perfusion. This results in the clinical signs of poor peripheral perfusion, such as a cold, pale, clammy, and mottled skin (1). Indexes of peripheral perfusion thus have been used to identify inadequate perfusion in critically ill patients (2–4). Peripheral perfusion can be assessed from clinical signs (1), from the central-to-toe temperature difference (2, 3, 5), or with techniques such as laser Doppler and capillary microscopy (6). Recently, the pulse oximetry signal has been suggested to reflect changes in peripheral perfusion (7). In addition, the ratio between the pulsatile and nonpulsatile component of the pulse oximetry signal has been related to peripheral perfusion (8). Because a pulse oximeter is universally available in the operating room and intensive care unit, this ratio could be used to monitor perfusion in these circumstances.

Although the manufacturer reports the lower and upper limit of normal to be 0.3 and 10.0, respectively, the variation in normal subjects and the clinical application of this ratio as an index of peripheral perfusion in critically ill patients have not yet been studied. The objective of the current study, therefore, was to assess the variation of this perfusion index in healthy adults and study the relationship between the peripheral perfusion index (PFI) and clinical signs of poor peripheral perfusion in critically ill patients.

METHODS

Participants

The study was conducted at a university-affiliated teaching hospital. Group 1 consisted of 108 healthy adult volunteers (mean age, 30 ± 9 yrs). Group 2 consisted of 37 critically ill patients (mean age, 70 ± 13 yrs) admitted to the medical/surgical intensive care unit.

Measurements

Group 1. The measurements included capillary refill time, PFI, and arterial oxygen sat-
perfusion pro

peripheral perfusion was abnormal; the second

patient. The

two measurements were taken from each pa-

ient. The Viridia/56S monitor (Philips Medical Systems). The

Viridia system calculates the PFI as the ratio

between the pulsatile component and the non-

pulsatile component of the light reaching the

light-sensitive cell of the pulse oximetry probe.

Group 2. The measurements included PFI,

Spo2, ambient temperature, central tempera-

ture, great toe temperature, finger tempera-

ture, capillary refill time, and hemodynamic

variables including heart rate and mean arte-

rial pressure. The central temperature was

measured by using either a pulmonary artery

catheter or a rectal probe. The peripheral tem-

perture was measured on the ventral face of

the great toe with a temperature probe (Phil-

ips Medical Systems 21078A). The finger tem-

perture was measured simultaneously with

the PFI measurement on the same finger by

using a similar probe. The central-to-toe tem-

perature difference was calculated, and a dif-

ference up to 7°C was considered normal (9).

The doses of vasoactive drugs were recorded.

Poor peripheral perfusion was defined as a

capillary refill time >2 secs or a central-to-toe

temperature difference ≥7°C.

Protocol

To evaluate the variation of the PFI in

healthy volunteers (group 1), measurements

were taken in the hospital restaurant before and

after their normal lunch after a 5- to 10-min

rest. Volunteers were seated and instructed to

keep their hands still on the table to avoid mo-

tion artifacts and to have the hands at the level of

the heart. A questionnaire was used to collect

information about history of smoking and vas-

cular disease (diabetes, hypertension). In group

2, two measurements were taken from each pa-

ient. The first measurement was taken when

peripheral perfusion was abnormal; the second

measurement was taken when the peripheral

perfusion profile had normalized. Patients with

central hypothermia (core temperature <36°C)

and limb ischemia attributable to vascular oc-

clusion were excluded.

Statistical Analysis

Data are presented as mean ± so and me-

dians with the 25th and 75th percentiles un-

less otherwise indicated. Differences between

groups or within groups were assessed by us-

ing the Mann-Whitney test for nonparametric

data. Pearson’s correlation index was calculat-

ed where applicable. We considered p < .05
to be statistically significant. Statistical anal-

yses were conducted with Statistical Package

for the Social Sciences version 9.0 (SPSS, Chi-

cago, IL).

Informed Consent

The Institutional Review Board waived the

need for written informed consent from the

healthy volunteers. Informed consent was ob-

tained from the relatives of the patients.

RESULTS

Group 1. One hundred and eight healthy volunteers were included, and a total of 216 measurements were made. The distribution of age in the healthy volunteers was normal: skewness, 0.06; median, 36 yrs (inner quartile range, 30–45 yrs). The distribution of PFI was skewed (Fig. 1, Table 1).

Descriptive analysis showed no signifi-

cant difference between variance and skew-

ness of the measurements before and after

the meal (Table 1). Also, no significant dif-

ferences were found between smokers (n =

26) and nonsmokers (n = 82), as well as be-

tween volunteers with (n = 11) or without

(n = 97) vascular disease (diabetes, hyper-
	ension). All volunteers had a normal capil-

lary refill time and arterial oxygen satu-

ration (96% to 100%).

Group 2. A total of 74 measurements were carried out in the 37 patients studied. Descriptive statistics revealed a mean PFI of 2.2 ± 0.22 with a median of 1.8

(inner quartile range, 0.5–3.2). Table 2

summarizes hemodynamic data during

abnormal peripheral perfusion and nor-

mal peripheral perfusion, as well as the

mean doses of vasoactive drugs. No sig-

nificant relationship between core tem-

perature and PFI or core-to-toe tempera-

ture difference was found. A significant

exponential relationship between PFI and

the core-to-toe temperature difference was

found (R2 = .52, p < .001; Fig. 2).

We found a significant linear correla-

tion between changes in PFI and changes

in the core-to-toe temperature difference

(R2 = .52, p < .001; Fig. 3).

In all cases, a concordant change in

Figure 1. Frequency distribution of all 216 peripheral perfusion index (PFI) measurements in healthy volunteers (group 1).

Table 1. Descriptive statistics of peripheral perfusion index (PFI) measurements in healthy volunteers (group 1).

<table>
<thead>
<tr>
<th>PFI</th>
<th>All Measurements (n = 216)</th>
<th>Before Meal (n = 108)</th>
<th>After Meal (n = 108)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.2 ± 2.0</td>
<td>2.2 ± 2.0</td>
<td>2.2 ± 1.9</td>
<td>NS</td>
</tr>
<tr>
<td>Median (IQR)</td>
<td>1.4 (0.7–3.0)</td>
<td>1.4 (0.6–3.2)</td>
<td>1.5 (0.8–2.8)</td>
<td>NS</td>
</tr>
<tr>
<td>P5–P95</td>
<td>0.2–6.0</td>
<td>0.4–6.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skewness</td>
<td>1.61 ± 2.44</td>
<td>1.50 ± 2.42</td>
<td>1.64 ± 2.42</td>
<td>NS</td>
</tr>
<tr>
<td>Variance</td>
<td>3.84</td>
<td>4.12</td>
<td>3.59</td>
<td>NS</td>
</tr>
</tbody>
</table>

IQR, inner quartile range; P5–P95, 5th and 95th percentiles; NS, not significant.

Table 2. Hemodynamics, variables of peripheral perfusion, and vasoactive medication during abnormal and normal peripheral perfusion in the 37 patients

<table>
<thead>
<tr>
<th>Variable</th>
<th>T1</th>
<th>T2</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core temperature, °C</td>
<td>37.5 ± 0.2</td>
<td>37.5 ± 0.1</td>
<td>NS</td>
</tr>
<tr>
<td>Heart rate, bpm</td>
<td>92 ± 3</td>
<td>91 ± 3</td>
<td>NS</td>
</tr>
<tr>
<td>Mean arterial pressure, mm Hg</td>
<td>81 ± 3</td>
<td>78 ± 2</td>
<td>NS</td>
</tr>
<tr>
<td>Spo2, %</td>
<td>97 ± 1</td>
<td>96 ± 0</td>
<td>NS</td>
</tr>
<tr>
<td>Core-to-toe temperature difference, °C</td>
<td>9.0 ± 0.45</td>
<td>4.9 ± 0.3</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Perfusion index</td>
<td>0.7 ± 0.1</td>
<td>3.6 ± 0.3</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Dopamine, μg/kg/min</td>
<td>2.5 ± 0.83</td>
<td>1.4 ± 0.44</td>
<td>NS</td>
</tr>
<tr>
<td>Dobutamine, μg/kg/min</td>
<td>2.9 ± 1.1</td>
<td>2.1 ± 0.5</td>
<td>NS</td>
</tr>
<tr>
<td>Noradrenaline, μg/kg/min</td>
<td>0.09 ± 0.03</td>
<td>0.05 ± 0.02</td>
<td>NS</td>
</tr>
</tbody>
</table>

T1, condition of abnormal peripheral perfusion; T2, condition of normal peripheral perfusion; Spo2, arterial oxygen saturation; NS, not significant.
PFI and core-to-toe temperature difference was found. No significant relationship was found between mean arterial pressures, dose of vasoactive agents, and PFI or between changes in these variables and changes in PFI.

In 16 patients, cardiac output was measured. No significant relationship was found between changes in cardiac output and changes in either core-to-toe temperature difference or PFI.

We assessed the ability of the PFI to indicate an abnormal peripheral perfusion, as reflected by an abnormal core-to-toe temperature difference by constructing a receiver operating characteristic curve. A PFI of 1.4 discriminated best between a normal and abnormal core-to-toe temperature difference in these critically ill patients (area under the curve, 0.91; 95% confidence interval, 0.84–0.98). Table 3 reports the corresponding sensitivity, specificity, and likelihood ratios.

**DISCUSSION**

We studied whether a perfusion index calculated from the pulse oximetry signal, and available on-line in some monitoring systems, can reflect clinical signs of decreased peripheral perfusion (capillary refill time and central-to-toe temperature difference) in critically ill patients. Because no data were available on normal values for this perfusion index, we also studied the variation of this variable in healthy individuals. We show that a PFI of 1.4 can be used to detect abnormal peripheral perfusion in critically ill patients, corresponding with the median value found in the healthy volunteers. In addition, changes in this perfusion index adequately reflect changes in clinical signs of peripheral perfusion and thus can be used to assess effect of therapeutic interventions on peripheral perfusion.

During circulatory failure associated with hypovolemia and low cardiac output, redistribution of blood flow caused by increased vasoconstriction results in decreased perfusion of the skin (1). Therefore, in critically ill patients, skin perfusion is frequently used to assess adequacy of global blood flow. Clinical signs of poor skin perfusion consist of a cold, pale, clammy, and mottled skin. Recently, techniques have become available to measure perfusion of the skin. Laser Doppler flow measurements and capillary microscopy (6) can adequately quantify changes in capillary blood flow but are not readily available in the emergency department or intensive care unit.

When blood supply to the skin decreases, the temperature of the skin also decreases. Therefore, measurements of skin temperature have been used to indicate decreases in skin blood flow as a marker of vasoconstriction and poor oxygen delivery (3, 2). Also, peripheral skin temperature has been advocated as a marker of the severity of shock (4). In addition, because vasoconstriction of the skin reduces body heat loss, the difference between the core temperature and skin temperature may increase. The central-to-toe temperature difference therefore has been used to diagnose and treat patients with global blood flow abnormalities (3, 5). To have this parameter of peripheral perfusion available online, at least two temperature probes are necessary, and the skin temperature probe should be carefully affixed. These requirements may limit the use of these variables in emergency situations and clinically unstable patients.

Pulse oximetry is a monitoring technique used in almost every trauma and critically ill patient. Monitoring of pulse oximetry during surgery is mandatory in many countries. The principle of the pulse oximetry is the difference in absorbance of light with different wavelengths (660 and 940 nm) by deoxygengenedoglobin. Other tissues, such as connective tissue, bone, and venous blood, also absorb light and thus affect the resulting signal. However, whereas the arterial component of the signal is pulsatile, the absorption of light by other tissues is fairly constant. To have a proper estimate of the arterial oxygen saturation of the hemoglobin, the pulse oximetry has to distinguish the pulsatile component from the nonpulsatile component, where the pulsatile component is used subsequently to calculate the arterial oxygen saturation (10, 11). When the signal is weak, for example, during vasoconstriction, the pulse oximetry signal requires amplification up to $10^9$ (10). Although analysis of the pulse oximeter waveform has been used to assess the volume status of patients during major surgery (7), the amplification necessary during a low signal (vasoconstriction, hypovolemia) could limit its clinical application in critically ill patients. The perfusion index, used in this study, is calculated as the ratio between the pulsatile and the nonpulsatile component of the light reaching the detector of the pulse oximeter. When peripheral hypoperfusion exists, the pulsatile...
component decreases, and because the nonpulsatile component does not change, the ratio decreases. Because the amplification necessary during the low signal affects both the pulsatile and nonpulsatile component, the ratio between these components is not affected. Although this variable has been incorporated in some monitoring systems as a parameter of peripheral perfusion, no data are available on the variation in the normal population. Also, no studies have been published on the relationship between the index and clinically used variables of peripheral perfusion in critically ill patients.

In the current study, we found a skewed and wide range of PFI values in healthy volunteers. We found no significant differences in the distribution of PFI values before or after a meal in this group of volunteers. Also, no differences were found between volunteers with or without chronic disease associated with vascular (or microvascular) abnormalities (e.g., hypertension, diabetes) or between smokers and nonsmokers. The variation in PFI was not related to differences in capillary refill times because these were all normal in the volunteers. Unfortunately, it was impossible to measure other indexes of peripheral perfusion, for example, the central-to-toe temperature difference in these volunteers.

By constructing a receiver operating characteristic, we found the median value of the healthy volunteers to be the best discriminating cutoff value to detect an abnormal core-to-toe temperature difference. This cutoff value also resulted in adequate predictability to detect an abnormal capillary refill time. Although this cutoff value suggests that 50% of the healthy volunteers had an abnormal peripheral perfusion, the two groups probably do not compare. Most of the critically ill patients were treated with vasoactive agents and were likely to have a disturbed regulation of peripheral circulation. Probably the cutoff value to detect abnormal peripheral circulation in the healthy volunteers is closer to the lower limit of normal reported by the manufacturer (0.3) representing the 5th percentile in our study. In addition, changes in clinical indicators of peripheral perfusion were met by concordant changes of the PFI in all patients.

Although poor peripheral perfusion often accompanies circulatory failure, the practical application of these indexes and the relationship with central hemodynamics or tissue oxygenation are not well studied. Assessment of capillary refill time has been found difficult in emergency situations, whereas the application of toe temperature measurements is very often limited in emergency medicine (12). In adult cardiac surgery patients and patients with cardiogenic shock, a crude correlation between the central-to-toe temperature difference and cardiac output has been reported (13, 2). In pediatric patients, both capillary refill time and the central-to-toe temperature difference was not related to global hemodynamics or blood lactate concentrations (14). However, in general pediatric patients, most of whom had septic shock, these indexes of peripheral perfusion correlated significantly with global hemodynamics and blood lactate concentrations (14). In contrast with this study, the central-to-toe temperature difference has been found of limited value in adult patients with septic shock (2). Also in our study, changes in cardiac output did not correlate with changes in clinical signs of poor peripheral perfusion or the PFI. These different findings could be related to the heterogeneity in skin blood flow regulation during changes in global blood flow and associated sympathetic nerve activity (15). Nevertheless, improvements in peripheral perfusion after treatment are associated with improved outcome in patients with circulatory shock (16). The PFI represents an easily obtainable measure of peripheral perfusion and thus could be used to monitor the effect of therapy on peripheral perfusion in critically ill patients.

CONCLUSION

Our results show that the PFI in normal populations has a highly skewed distribution. The best discriminating value to detect an abnormal peripheral perfusion in critically ill patients equals the median value of normal volunteers but nevertheless can adequately reflect the presence of clinical indicators of poor peripheral perfusion in critically ill patients. Changes in these clinical indicators are reflected by changes in the PFI. Therefore, this easily obtainable and noninvasive method may have a role in monitoring peripheral perfusion in critically ill patients.

REFERENCES