Original Contribution

Comparison of Doppler Ultrasound, Photoplethysmographic, and Pulse-Oximetric Calculated Pressure Indices To Detect Peripheral Arterial Occlusive Disease

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Abstract

Objectives. Doppler ankle-brachial pressure index (ABI) is considered the non-invasive screening test of choice to detect peripheral arterial disease (PAD). Photoplethysmography (PPG) and pulse oximetry (PO) are also suitable alternatives; however, correlation and validation are yet to be established. We compare Doppler ABI, PPG-derived and PO-derived indices to detect PAD.

Design. Prospective case control study.

Methods. Forty-six subjects were evaluated by PO, PPG, and Doppler ABI. Twenty-three patients had known PAD and 24 were healthy subjects with no signs of PAD. Pressure in arms, fingers, toes, and ankles were measured, and different pressure indices calculated.

Results. Groups of control participants and patients with peripheral vascular disease were significantly different with regards to age, prevalence of diabetes, and prevalence of hypertension. Doppler ABI was most sensitive (81.4%) to diagnose PAD in the main study group (n = 46). In patients with diabetes and/or chronic renal failure, Doppler ABI had lower sensitivity (69.2–71.4%) and was comparable to the other diagnostic tests; photoplethysmography toe-finger index (TFI) achieved the highest sensitivity in these patients (84.6–85.7%).

Conclusions. Doppler ABI had the highest sensitivity to diagnose PAD overall. In patients with diabetes and/or chronic renal failure, Doppler ABI had lower sensitivity and was comparable to most of the other diagnostic tests. PPG TFI may provide greater sensitivity in the screening of patients with diabetes and CRF for PVD. This pilot study is relatively small and findings should be further investigated with a larger trial.

Introduction

Peripheral arterial disease (PAD) is an important health problem worldwide, causing significant morbidity and decreasing quality of life. Diabetic patients warrant special consideration, since they are more likely to develop PAD. Also, diabetics are at risk of premature development of minor and major morbidity, including amputation.

There are many non-invasive tests to evaluate patients with limb ischemia.

1. Peripheral arterial duplex scanning is reliable on a single-patient basis. However, the high cost of this test and the complexity of its performance make it inadequate for screening (Table 1).

2. Doppler ankle-brachial pressure index (ABI) is the method of choice to screen for PAD. However, its reliability may be questioned since data supporting its validity mainly arises from studies on symptomatic patients. Also, validity of ABI is diminished in diabetes and dependent on technique.

3. Pulse oximetry (PO) toe-brachial pressure index (PO-TBI) and PPG toe-brachial pressure index (PPG-TBI) may be alternative screening tests for PAD. Their reliability and effectiveness has been widely demonstrated and as a result, these tests have gained recognition in assessment of chronic limb ischemia. As opposed to PPG, PO uses simple equipment available in many clinical settings. Additionally, most health care personnel are familiar with the use of pulse oximeters.

Since Doppler ABI is unreliable in diabetes and renal failure, it is necessary to establish a simple, non-invasive and low-cost screening test for PAD. This study compares Doppler ultrasound, PO, and PPG limb pressure indices to detect PAD in asymptomatic, healthy volunteers and symptomatic patients with PAD.

Patients and Methods

Healthy volunteers and patients with symptoms of peripheral arterial disease who had previously been diagnosed using Doppler ABI, PPG toe pressures, or duplex ultrasonography were invited to participate in this prospective case control study. Informed consent and ethical approval was obtained. Participants were evaluated by pulse oximetric, photoplethysmographic, and Doppler ultrasonic measurement of
ankle, brachial, finger, and toe blood pressures (Figure 1).

**Doppler ankle-brachial pressure index (ABPI).** ABPI was measured with a handheld Multi Dopplex II bi-directional Doppler (Huntleigh Healthcare Ltd., Cardiff, United Kingdom). A 8-MHz Doppler probe was used. A standard 14-cm pressure cuff (Speidel & Keller, Welch Allyn, Ltd., Jungingen, Germany) and an analogue sphygmomanometer (FemoStop, Radi Medical Systems, Upplands, Sweden) were used.

**Pulse oximetry (PO).** Measurement of PO toe and finger pressures was performed with a handheld pulse oximeter (Biox 3700e, Ohmeda, Louisville, Colorado), two pulse oximetry probes (Viamed P867RA, West Yorkshire, United Kingdom), and a sphygmomanometer (FemoStop). The 95-mm pressure cuffs were selected from three different sizes according to the toe or finger length, and diameter (16 mm, 19 mm, and 25 mm wide). The 14-cm pressure cuff, and a sphygmomanometer were used to measure ankle and brachial pressures.

**Photoplethysmography (PPG).** PPG is based on detecting changes in blood filling of the digit. The PPG sensor emits infrared light which is then reflected back from red blood cells. The more red blood cells present, the greater the reflected signal. A photoplethysmography device and two PPG probes (Dopplex Assist Range: PPG Assist, APPG 10A00007-00; Huntleigh Healthcare, Ltd.), a 95-mm long pressure cuff, and a sphygmomanometer were used to measure toe and finger pressures. The 95-mm pressure cuffs were chosen from three different sizes according to the toe or finger length, and diameter (16 mm, 19 mm, and 25 mm wide). The PPG signal is displayed on an electronic display and recorded on a paper recorder.

To determine ankle and brachial pressures, a 14-cm pressure cuff and an analogue sphygmomanometer were used.

**Measurement protocol.** All patients were examined supine following ten minutes rest. Ambient temperature was 22°C. All measurements were performed consecutively on the same day by an unblinded single examiner. Assessments followed a standardized order. PO assessment was performed first, followed by PPG, then ABPI. For each investigation, toe pressures were recorded first, followed by finger, ankle and brachial pressures.

PO probes were placed over the distal parts of both great toes or index fingers, aligning the emitter light with the center of the nail, and pressure cuffs were placed around the proximal phalanges. When a good signal was detected on the pulse oximeter screen.

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**Table 1. Approximate cost of equipment used in non-invasive vascular assessment.**

<table>
<thead>
<tr>
<th>Equipment</th>
<th>US dollars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duplex ultrasound scanner</td>
<td>&gt; 20,000</td>
</tr>
<tr>
<td>PPG</td>
<td>~4000</td>
</tr>
<tr>
<td>Hand-held Doppler US</td>
<td>~1000</td>
</tr>
<tr>
<td>Pulse oximetry</td>
<td>~300</td>
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</tbody>
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**PPG = photoplethysmography**

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**Figure 1.** Diagram of the study design. US = ultrasound; PPG = photoplethysmography; ABI = ankle-brachial pressure index; TBI = toe-brachial pressure index; TFI = toe-finger pressure index.
presence or absence of peripheral arterial disease. The groups were significantly different with regards to age ($P = 0.00001$), prevalence of diabetes mellitus ($P = 0.0001$), and prevalence of hypertension ($P = 0.003$). Other variables, such as sex, body mass index (BMI), smoking status, and prevalence of end-stage renal disease were not significantly different (Table 2).

Diagnostic performance of ABI assessed by three modalities for PAD. The prevalence of PAD in the study population was 48%. Doppler ultrasound ABI was considered to be the gold standard. It had a sensitivity of 81.4% and a specificity of 100%. The PPV (100%) and the NPV (87.5%) were also high. Positive likelihood ratio (LR+) could not be calculated for Doppler ABI and for PO/Doppler ABI.

Table 3 illustrates the diagnostic performance (sensitivity, specificity, PPV, NPV) of ABI measured with PO, PPG and Doppler ultrasound. Indices combining PO or PPG ankle pressures with Doppler brachial pressures (PO/D and PPG/D ABI) are also shown. Doppler ABI had the highest sensitivity and all other modalities had similarly lower sensitivities. After
Doppler ABI, the highest specificity was achieved with PO/D ABI (91.7%), followed by PPG ABI (75%).

Diagnostic performance of TBI and TFI assessed by three modalities for PAD. Table 4 shows the diagnostic performance (sensitivity, specificity, PPV, NPV) of TBI and TFI measured with PO and photoplethysmography. Indices combining pulse oximetry toe pressures with Doppler brachial pressures (PO/DOP TBI), and photoplethysmography toe pressures with Doppler brachial pressures (PPG/DOP TBI) are shown as well. Sensitivity of these indices was relatively low, and the highest was obtained with PPG TFI. On the other hand, specificities were high, with PO/DOP TBI reaching 100%. While the positive predictive value was high for most modalities, the negative predictive value was lower and comparable among these tests.

Diagnostic performance of tests to diagnose PAD in diabetes mellitus and/or chronic renal failure. Data from patients with diabetes mellitus (n = 13) and/or chronic renal failure (n = 6) was analyzed as a subset. Demographic data is presented in Table 5.

A total of 16 participants were identified and only two did not have a diagnosis of PAD (Doppler ABI > 0.90). Prevalence of PAD was 87.5%.

In patients with chronic renal failure and diabetes, PPG TFI showed the highest sensitivity (85.7%), and an excellent specificity (100%). This was followed by PPG/D ABI. The PPV for PPG TFI, despite being relatively low (50%), was also the highest among these tests for this population. When sensitivities were calculated in just those patients with diabetes, similar findings were seen. PPG TFI had the highest sensitivity (84.6%), followed by PPG/D ABI (79.6%). The Doppler ABI, PPG ABI, and PPG/D TBI had similar sensitivities (69.2%). The lowest sensitivity was obtained with PO/D TBI (46.2%).

Discussion

The participants with PAD in this study were significantly different than those without PAD with regard to age, prevalence of diabetes, and prevalence of hypertension.

Doppler ABI had the highest sensitivity to diagnose PAD overall (Table 3). In patients with diabetes and/or chronic renal failure, Doppler ABI had lower sensitivity and was comparable to most of the other diagnostic tests. This is similar to the findings of Aboyan et al, who showed that in a group of 510 ambulatory patients, diabetes was the dominant risk factor for a high (>1.4) ABPI reading, thus confounding the sensitivity for PAD. Similarly, a Spanish study reported that the usual linear correlation between ABPI and TBI did not exist in the presence of arterial wall calcification. Furthermore, a Japanese case control study showed that in type 2 diabetics, PAD, despite normal ABPI, was associated with increased arterial wall stiffness.

The necessity of warming the foot to get an acceptable PO reading corresponds to a study assessing PO in the pre-hospital setting. The authors report that...
without active warming, there was an almost three-fold increase in malfunction time compared to actively warmed patients.\(^\text{11}\) Such high incidences of poor recording and necessity for applying active warming may well make PO difficult to use and unsuitable for screening purposes.

In patients with diabetes and/or chronic renal disease, PPG TFI achieved the higher sensitivity in these groups (85.7\%, Table 6). It is noteworthy that the sensitivities of TBI measured using PO or PPG was considerably lower (61.5\% and 71.4\%, respectively). Our findings suggest that the PPG TFI is a more sensitive screening tool for PAD in diabetes and CRF. The increased sensitivity may be related to age and disease-related decrease in compliance, and the altered character of the small vessels at the extremities.\(^\text{12}\) This differs from previous reports suggesting that TBI is the most appropriate screening test in this setting.\(^\text{13}\) PPG has been shown to be an easy-to-learn and reliable test,\(^\text{14}\) and may be used for TFI measurements in screening patients with diabetes and CRF for PVD. We acknowledge that this study should be interpreted as a pilot study and that the number of participants with diabetes and chronic renal failure is small. The findings should be further investigated with a larger trial.

**References**