Measuring Toe Pressures Using a Portable Photoplethysmograph to Detect Arterial Disease in High-risk Patients: An Overview of the Literature

Phyllis Bonham, PhD, MSN, RN, CWOCN, DPNAP, FAAN

Abstract
Lower extremity arterial disease (LEAD) is estimated to affect one third of individuals older than 65 years of age, occurs in younger individuals who use tobacco or have diabetes mellitus (DM), and often remains undiagnosed until a patient presents with ischemia-related symptoms or complications. Valid and reliable noninvasive tests such as the ankle-brachial index (ABI) are recommended to detect LEAD. However, ABI results can be inconclusive or the index can be elevated (ie, >1.3) in persons with calcified ankle arteries due to DM, renal failure, or arthritis. In these instances, obtaining toe pressure (TP) measurements, which correlate well with angiographic findings, is advised, providing the patient does not have vasoconstriction with cold toes or vasospastic disease. In such cases, TP can be obtained using a portable photoplethysmograph (PPG), which offers a simple and inexpensive method for healthcare providers in a variety of clinical settings to assess for the presence of LEAD. Portable PPG TP measurements have been found to have a high level of agreement with vascular laboratory PPG tests to detect LEAD, as well as good sensitivity and a high specificity. Adopting a TP measurement protocol of care to assess high-risk individuals such as patients with DM and elevated ABIs potentially can have a major impact on early identification of LEAD and reduce the risk of ischemia-related complications, including lower extremity wounds and amputations.

Keywords: lower extremity arterial disease, diabetes mellitus, assessment, screening, toe pressure


Potential Conflicts of Interest: none disclosed

Lower extremity arterial disease (LEAD), also known as peripheral arterial disease (PAD), is a chronic, progressive disorder related primarily to atherosclerosis. The disease is estimated to affect 10% to 15% of the US population\(^1\) and up to 30% of adults older than 65 years of age worldwide.\(^2\)-\(^9\) LEAD also occurs in persons younger than 60 years who use tobacco or have diabetes mellitus (DM).\(^10\) Up to 25% of persons with LEAD will develop critical limb ischemia within 5 years of onset\(^11\) and 3% to 8% will have limb loss.\(^12\) For persons with DM, LEAD is a problematic coexisting condition. In 2007, $116 billion was expended in the US for direct costs of treating DM and its complications, and $58 billion was lost in reduced national productivity.\(^13\)

Unfortunately, LEAD is often not recognized by many patients or physicians until a complication such as severe pain, a nonhealing wound, or infection leading to limb loss occurs. According to a review of epidemiologic studies by Criqui,\(^14\) individuals with reduced arterial perfusion can be asymptomatic because <50% of persons with LEAD exhibit its classic symptom of intermittent claudication (ie, calf pain with exercise); leg pains are often mistaken for normal aging or arthritis. Several studies (see Table 1)\(^17,15-22\) have shown LEAD can be asymptomatic and not diagnosed in up to approximately 50% of patients when measures such as pulse palpation or a history of claudication are relied on to diagnose LEAD instead of using more reliable tests such as ankle-brachial index (ABI). Also, Hirsch et al\(^15\) reported that many physicians fail to treat LEAD, even after it is identified, as aggressivel as cardiovascular disease. LEAD is a marker of systemic atherosclerosis, and asymptomatic as well as symptomatic individuals have the same increased risk of cardiovascular or cerebrovascular morbidity and mortality.\(^7,23-25\)

Early diagnosis of LEAD is important to implementing behavioral changes to reduce its modifiable risk factors, including tobacco use, hypertension, hyperlipidemia, hyperhomocysteinemia, and hyperglycemia.\(^26,27\) Experts stress prevention and not waiting until ischemia, pain, or wounds develop.\(^28,29\)
Data regarding the precise number of wounds in the US due to LEAD are not available. Some authors have estimated that one third of patients with DM have ischemia that causes amputations.\(^{4,5,30}\) A review by Dillingham\(^{31}\) of 1988–1996 hospital discharge data reported that ischemia was the underlying cause of limb loss in 82% of patients. Therefore, knowing the extent of LEAD is vital to prevention; if a lower extremity wound develops, perfusion status helps gauge the healing potential and guide therapeutic interventions such as debridement, compression, adjunctive treatments, and surgical intervention.\(^{25}\)

Noninvasive tests such as ABI are recommended to assess for LEAD in high-risk individuals.\(^{26,32-35}\) The ABI is a ratio derived by comparing systolic blood pressure measurements in each ankle to the higher pressures of the arm (ie, higher of each ankle pressure divided by the higher arm pressure = ABI). If blood flow is normal in the lower extremity, the ankle pressure is equal or slightly higher than in the arm with an ABI of 1.0.\(^{46}\) ABI values are described as elevated (ABI >1.3), normal (ABI >1.0); LEAD (ABI <0.9), borderline perfusion (ABI <0.6 to 0.8), severe ischemia (ABI <0.5), and critical ischemia (ABI <0.4).\(^{26}\)

An alternative assessment involves toe pressure (TP), which can be obtained via Doppler, volume plethysmography, or photoplethysmography (PPG). If the ABI is elevated (>1.3), which can occur when ankle arteries are calcified, TP or a toe brachial index (TBI) are options to detect LEAD.\(^{36-42}\) ABI and TP/TBI tests correlate well with angiographically proven LEAD.\(^{12,14,37,42}\)

Despite the attention given to the high prevalence of undiagnosed LEAD and the value of ABI/TBI mentioned in several national guidelines,\(^{35,43-46}\) as well as a position statement by the Society of Cardiovascular and Interventional Radiology,\(^{33}\) healthcare providers have not adopted these tests into routine practice. In a survey of primary care practices, Hirsch et al\(^{15}\) reported that ABIs were not routinely performed. In a survey of 50 nurses, Vówden and Vówden\(^{47}\) reported an overall lack of knowledge about how to correctly perform ABI.

In vascular laboratories, TPs are routinely measured with standard laboratory PPG equipment because results are more reliable than when using Dopplers.\(^{46}\) Although multiple studies address volume/photo plethysmography, there is a paucity of literature regarding the extent of Doppler or portable PPG use beyond vascular laboratory settings. The purpose of this overview is to summarize the literature about the role of ABI and TP measurements used to assess for the presence of LEAD in general, and the potential benefits of using PPG to measure TP when ABIs cannot be measured or are elevated in particular.

Risks and Impact of LEAD

**Risk factors.** Multiple risk factors for the development of LEAD have been identified, including tobacco use, advanced age, DM, hyperlipidemia, hypertension, hyperhomocysteinemia, African American ethnicity, a family history of cardiovascular disease, and renal insufficiency.\(^{26,32}\) A recent prospective study\(^{32}\) designed to explore the benefits of ABI screening in 107 randomly selected, asymptomatic patients between 50 and 70 years of age identified age, DM, and smoking as the strongest predictors of LEAD.

DM increases the risk of LEAD four-fold.\(^{26}\) In patients with DM, LEAD has an earlier onset, progresses faster, commonly involves the infrapopliteal vessels, affects both large and small vessels, and is usually bilateral, compared to persons without DM.\(^{48,49}\) According to the American College of Cardiology/American Heart Association (ACC/AHA)\(^{45}\) guidelines for management of patients with PAD, patients with LEAD and DM have a seven- to 15-fold greater risk of a major amputation compared to persons without DM. A recent prospective, community based, observational study\(^{34}\) of patients with DM (N = 1,294) found that the prevalence of LEAD was 13.6% and that persons with an ABI <0.9 had double the rate of gangrene and amputations compared to persons with an ABI >0.9.

A 7-year prospective study\(^{49}\) of patients with (n = 146) and without (n = 113) DM found that the prevalence of LEAD (ABI <0.9) varied from 28.6% in the right posterior tibial artery to 48% in the left peroneal artery, and a high mortality rate was noted due to cerebral and cardiovascular disease. When mortality rates were compared, the rates for patients with and without DM were 34% and 13%, respectively (P < 0.001); the authors attributed the significant difference to the presence of arterial disease in persons with DM.

Impact. Studies\(^{50-52}\) have identified that LEAD impacts the quality of life of individuals. Arseken et al\(^{50}\) used a prospective, cross-sectional study design with a cohort of men and women with (n = 93) and without (n = 74) LEAD and found that patients with LEAD had depressive mood twice as often as controls (24% versus 12%, P = 0.06). Breek et al\(^{51}\) conducted a prospective observational study of 200 consecutive patients with intermittent claudication seen in a...
### Table 1. Summary of literature on undiagnosed/asymptomatic LEAD

<table>
<thead>
<tr>
<th>Author</th>
<th>Study type/design</th>
<th>Sample- size</th>
<th>Methods/data</th>
<th>Results</th>
</tr>
</thead>
</table>
| Fowkes G, Low L, Tuta S, Kozak J (2006) | International prospective, multicenter study in 24 countries to assess extent of atherothrombosis in patients with or without/at risk of vascular disease: part of A Global Atherothrombosis Assessment (AGATHA) study | N = 8,891 patients consecutively recruited (n =1,792 at risk; n =7,099 with disease) | • History, clinical assessment  
  • ABI measured                           | • Abnormal ABI (<0.9) was found in 30.9% of at-risk, asymptomatic patients and in 40.5% with history of vascular disease |
| Hirsch A, Criqui M, Treat-Jacobson, et al (2001) | Multicenter, cross-sectional study at 27 sites in 25 cities in the US, June–October, 1999 to examine LEAD detection, awareness, and treatment in primary care (study part of the PAD Awareness, Risk, and Treatment: New Resources for Survival [PARTNERS] program) | N = 6,979 patients 70 years of age or older, or aged 50 through 69 years of age who had DM or smoked | • Obtained and evaluated history  
  • Measured ABI                             | • LEAD was detected in 29% (n =1,865) by ABI <0.9 | 83% of patients with prior LEAD were aware of their diagnosis, but only 49% of their physicians were aware of the diagnosis  
• Classic claudication was reported in only 11% of patients with LEAD  
• Patients with a prior diagnosis of LEAD were less intensively treated than patients with cardiovascular disease |
| Aboyans V, Lacrois P, Postil A, Guilloux J, et al (2005) | Prospective study to determine the ability of ABI to detect candidates for CABG with asymptomatic LEAD | N = 1,002 patients (mean age 66.9 + 9.2 years) undergoing CABG were consecutively enrolled in the study | • Measured ABI preoperatively  
  • History, clinical examination                  | • Detected subclinical LEAD in 13% (ie, patients without clinical symptoms but an ABI <0.85) |  
• Detected medial artery calcification in 12% (ie, audible pulse by Doppler signal even when the cuff was inflated >300 mm Hg and/or an ABI >1.5)  |
| Dieter R, Thomasson J, Gudjonsson T, et al (2003) | Prospective study to determine the prevalence of LEAD in hospitalized patients with CAD | N = 100 (66 men; 34 women) who were medically stable and hospitalized with CAD  | • History cardiovascular risk factors, history of LEAD  
  • Physical exam  
  • Measured ABI                             | • 40 patients (40%) were found to have LEAD (ABI <0.9) | Only 52.5% (n = 21) of the patients with LEAD were diagnosed |
<table>
<thead>
<tr>
<th>Author</th>
<th>Study type/design</th>
<th>Sample-size</th>
<th>Methods/data</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eason S, Petersen N, Suarez-Almazor, M Davis B, Collins T (2005)(^{18})</td>
<td>Cross-sectional study from four primary care centers to examine diabetes, smoking and the risk factors associated with asymptomatic LEAD</td>
<td>N = 403 patients 50 years of age and older (white, African American, and Hispanic participants)</td>
<td>• Obtained history of co-existing medical conditions (ie, DM), lifestyle factors (eg, smoking) • Measured ABI</td>
<td>• 25 (6.2%) had asymptomatic LEAD based on ABI &lt;0.9 • DM and history of smoking at least one pack of cigarettes per day were significantly associated with asymptomatic LEAD</td>
</tr>
<tr>
<td>Goessens B, Visseren F, Algra A, Banga J, van der Graaf Y (2006)(^{19})</td>
<td>Prospective study to assess the prevalence of atherosclerotic risk factors and the value of noninvasive imaging to detect asymptomatic cardiovascular disease in high and low risk patients</td>
<td>N = 3,950 patients aged 18–79 years with a diagnosis of CAD, cerebrovascular disease, abdominal aortic syndrome, LEAD, hypertension, hyperlipidemia, or DM</td>
<td>• Subjects were assessed for atherosclerotic risk factors • European Guideline on Cardiovascular Disease was used to classify patients as high or low risk • ABI was measured</td>
<td>• Asymptomatic LEAD (ABI &lt; 0.9) was found in 21% of the patients and was most frequently observed in patients with cerebrovascular disease</td>
</tr>
<tr>
<td>He Y, Jiang Y, Wang J, Fan L, Li X, Fu F (2006)(^{20})</td>
<td>Population based cross-sectional study in Beijing, China to identify the prevalence of LEAD and its association with smoking in 2001-2002</td>
<td>N = 2,334 subjects aged &gt;60 years (943 men; 1,391 women)</td>
<td>• Measured symptoms of IC by WHO/Rose questionnaire • Measured ABI</td>
<td>• Prevalence of LEAD by history of IC was 11.3%; 15.3% by ABI (&lt;0.9); and 19.8% by both criteria (ABI and history IC) • 40% of patients with LEAD were asymptomatic and unaware of their condition</td>
</tr>
<tr>
<td>Heidrich H, Wenk R, Hesse P (2004)(^{21})</td>
<td>Prospective, 1-year study (January 1994-January 1995) to identify the frequency of asymptomatic LEAD in patients being treated for varied internal diseases</td>
<td>N = 990 patients (51.8% women, 48.2% men; mean age 65.2 years) who were being treated in a general care hospital (ie, general and internal medicine departments)</td>
<td>• History and clinical exam • ABI performed</td>
<td>• 6% (n = 59) of the 990 had symptomatic LEAD • Based on ABI (&lt;0.9), of the remaining 931 patients, 43.7% (n = 406) were diagnosed with asymptomatic LEAD</td>
</tr>
<tr>
<td>Mourad J, Cacoub P, Collet J, et al (2009)(^{22})</td>
<td>Prospective, observational, epidemiologic study to determine the benefit of using ABI to screen for unrecognized LEAD</td>
<td>N = 2,146 asymptomatic patients &gt;55 years of age at high risk of cardiovascular disease and hospitalized in an urban French hospital (ie, cardiology, diabetology, geriatrics, internal medicine, and neurology departments)</td>
<td>• ABI measured • History, clinical examination</td>
<td>ABI was &lt;0.9 in 41.1% of the patients</td>
</tr>
</tbody>
</table>

ABI = ankle-brachial index; CABG = coronary artery bypass graft; CAD = coronary artery disease; DM = diabetes mellitus; IC = intermittent claudication; LEAD = lower extremity arterial disease
Table 2. Procedure: measuring toe pressures with a portable photoplethysmograph (PPG)*

**Prepare Equipment, Supplies, and Room**

1. Organize equipment and supplies: portable PPG and chart recorder, aneroid sphygmomanometer, digital cuffs (1.9–2.5 cm width), double stick tape to affix photo-sensor to toe, disposable gloves, sheets, blankets, and towels to cover trunk and lower extremities, paper and pen for recording the measurements, and chart recorder paper.

2. Charge battery for PPG/chart recorder.

3. Inspect the PPG and sensor, pressure cuffs, and sphygmomanometer for damage and replace if damaged.

4. Check the chart recorder and install paper.

5. Set the room thermostat to achieve a minimum room temperature of 21˚ to 23˚ + 1˚ C (68˚ to 75˚ F) to ensure a warm environment.

**Prepare the Patient**

1. Help patient remove shoes, socks, and restrictive clothing.

2. Help patient into a reclining, supine position with the toes at heart level and pointed to the ceiling to prevent hydrostatic effects on the pressure readings.

3. Place one small, flat pillow under the head for comfort.

4. Place pressure cuffs around the base of the right and left toes: 2.5 cm width for hallux (great toe) or 1.9 cm for the second toe.

5. Tape the PPG photosensor on the great toe or second toe if necessary.

6. Cover the trunk and extremities with towels, sheets, or blankets to prevent cooling.

7. Ensure the patient is comfortable.

8. Have the patient rest for a minimum of 10 minutes to stabilize the blood pressure.

9. Avoid conversation during the examination to reduce measurement variability.

**Measure Toe Pressures**

1. Inflate the pressure cuff on the right toe to a maximum of 200 mm Hg and slowly deflate the cuff until the pulse wave signal returns on the PPG chart recorder.

2. Record the point at which the arterial pulse wave signal first returns as the toe systolic pressure for the right toe.

3. Repeat steps 1 and 2 for the left toe.

4. Remove the cuffs, photosensors, and tape from the toes.

vascular outpatient department to assess the impact of walking impairment, cardiovascular risk factors, and comorbidity on quality of life. The authors reported the degree of pain, concomitant risk factors, and other comorbidities associated with LEAD negatively affected quality of life. In a qualitative study using grounded theory methodology, Treat-Jacobson et al. interviewed 38 patients to evaluate the effects of LEAD on their perceived quality of life. The authors identified several areas of concern expressed by the patients: frustration with delayed diagnosis and management of the disease, pain, limits in physical, social, and role function; feelings of a compromised self, uncertainty, and fear; and difficulty adapting to the effects of the disease.

In addition to their effects on patients’ quality of life, leg wounds represent a substantial financial burden. Although the exact costs of LEAD in the US are unknown, Miller and Phillips, using information from European sources, estimated that leg wounds (of varied types) cost approximately $1 billion in the US annually and cause two million lost workdays. In a descriptive survey of 192 home care patients with leg ulcers in Canada (38 arterial, 20%; 34 mixed arterial and venous, 18%; 108 venous, 56%; and 12 diabetic, 6%), the average cost of supplies for 1 month was $123.00 (US). On average, the patients had 12 home care visits per month at a cost of $274.00 (US) per visit. The costs according to the specific type of wound were not provided.

Assessment of LEAD

Ankle-brachial pressure. ABI is a simple noninvasive test that can be measured by healthcare providers in an clinical setting using portable equipment. ABI is measured with the patient in a resting, supine position using pressure cuffs at the ankles and arms and a continuous wave Doppler to detect the movement of red blood cells in the artery. A recent within-subjects comparative study of 30 patients referred to a vascular laboratory confirmed that the ABI measured by a nurse with a portable, hand-held, pocket Doppler following a research-based protocol was reliable and valid compared to ABI tests performed by a registered vascular technologist using standard laboratory equipment.

ABI assessment is recommended for patients at high risk for LEAD and cardiovascular disease, patients with lower extremity wounds, and patients with DM, because pulse palpation and a history of claudication are not sensitive indicators of LEAD. Pulse palpation is unreliable due to variations in clinicians’ ability to palpate pulses and because the dorsalis pedis pulse is congenitally absent in 4% to 12% of individuals. In a prospective study of 133 patients with arteriographically proven LEAD that were compared to 34 control normal volunteers, the ABI was shown to be 94% sensitive and 99% specific to detect LEAD.

ABI limitations. Studies have found an elevated ABI (>1.3) in some patients with DM, renal insufficiency, and rheumatoid arthritis due to calcification of the medial artery that can occur in these disease processes. The calcification renders the vessels noncompressible, resulting in an elevated reading. In a prospective study comparing ABI and TBI in patients with (n = 174) and without (n = 53) DM, Brooks et al. found ABI was elevated (>1.3) in 16 persons with DM. In a cross-sectional study, O’Hare et al. examined the association of LEAD (ie, ABI <0.9) and renal insufficiency among participants in the 1999–2000 National Health and Nutrition Examination Survey and reported 81 of 2,229 participants had an ABI >1.3 recorded for at least one leg. A prospective study by del Rincon et al. compared ABI in patients with (n = 931 arteries) and without (n = 408 arteries) rheumatoid arthritis (RA). The authors reported 79% (n = 66) of patients with RA had an ABI >1.3 compared to 0.7% (n = 408) of the controls who had ABI <1.3 (P = 0.002). Silvestro et al. prospectively collected data including ABI and TBI on 229 patients with critical limb ischemia; 107 patients had DM. The authors found that ABI was >1.3 in 45 patients and that it was significantly associated with DM (P = 0.01), renal insufficiency (P = 0.035), and a higher amputation rate (P = 0.0002).

In a prospective clinical study comparing various noninvasive tests to findings of multidetector-row computed tomography in hemodialysis patients (N = 36), Okamoto et al. reported that ABI sensitivity to detect LEAD was low (29.9%) in patients with DM, renal failure, or on hemodialysis. Findings from a recent retrospective clinical study of patients (N = 1,762), referred to a vascular laboratory for diagnostic tests revealed elevated ABI prevalence was 8.4%, and the prevalence of LEAD in patients with an elevated ABI was 62.2%, as confirmed by a TBI <0.60. Consequently, alternative tests are needed when an ABI is elevated or cannot be performed due to the presence of wounds at the ankle.

TP. TPs have been used for more than 80 years to assess for the presence of arterial disease. They provide an alternative site for testing and are recommended for individuals with an elevated ABI because prospective, clinical studies measuring and comparing the ABI and TBI have shown that digital (toe) arteries are usually less affected by calcification and incompressibility than ankle arteries.

TP can be used to calculate a TBI by dividing the TP by the higher brachial pressure; a TBI <0.64 indicates LEAD. It should be noted that TP measurement methods affect the validity and reliability of the findings.

TPs have been measured in vascular laboratories in a variety of ways, including strain gauge, volume plethysmography, and PPG. For volume plethysmography, a strain gauge is wrapped around the digit to measure changes in the circumference, which indicate the volume of blood flow in the tissues. In PPG, a transducer attached to the distal toe pad that sends infrared light into the underlying tissue with a light-emitting diode is used to detect pulsatile cutaneous blood flow. An adjacent photocell receives the backscattered infrared light and measures the reflection, which increases as cutaneous flow increases.
Dopplers also can be used as flow detectors to measure systolic TP. In the previously described prospective, comparative study by Brooks et al,4 the authors found no significant differences between results obtained using either the PPG or Doppler probe, although they did not specifically report the results by measurement method. By contrast, Kroger et al65 prospectively examined and compared Doppler to optical sensors to measure TP in 50 subjects. The authors reported the Doppler technique was unable to measure TPs in 29 of 50 patients with arterial disease and concluded that TPs were more useful to exclude limb ischemia than to diagnose it. Likewise, in a within-subjects comparative study of 30 patients, Bonham et al66 compared TP measured by a hand-held Doppler to standard vascular laboratory PPG tests and found that Doppler-derived TPs were unreliable due to vasoconstriction in cold toes and/or it was difficult to detect low flow in the small digital arteries. For example, if continuous-wave Dopplers are used to measure TPs and the toes are cold, causing vasoconstriction and restricting the movement of red blood cells through the artery, the TP can be low or undetectable.36,65 Therefore, it is unknown whether the low pressure is due to LEAD or the cold induced vasoconstriction.36,65 Because of the limitations of TP measured by continuous-wave Dopplers, reliable alternatives to measure TP, such as a PPG, are needed.

PPGs. TPs are commonly measured in vascular laboratories by trained, experienced staff using nonportable PPG equipment. For PPG measurement, a photosensor is placed on the distal pad of the first great toe (big toe/hallux) or second toe if the first toe is absent or unable to be used (eg, presence of a wound) to record pulse changes; a small, digital pressure cuff, the first reappearance of the pulse waveform on the PPG recorder represents the systolic pressure for the toe.25,37,63 For TP tests, the patient should be in the supine position with the toes at heart level and, if necessary for comfort, the head can be elevated 10° to 20°.63 Carter and Lezack41 prospectively measured TPs and performed angiography and reported that the TPs correlated well with angiographic findings in 102 limbs. According to Carter,37 50 mm Hg is the lower limit of normal for TP. An absolute systolic TP <30 mm Hg (<50 mm Hg for patients with DM) is indicative of critical limb ischemia and predictive of nonhealing wounds.4,44,64,66 Findings from Bonham et al’s25 recent within-subjects comparative study that compared TP measurements obtained with a portable PPG (N = 58) to pressures measured using standard vascular laboratory PPG equipment indicated a substantial level of interobserver agreement of 90% (52 out of 58) between the tests to detect LEAD (ie, TP <50 mm Hg) with a Kappa statistic of 0.76. Additionally, compared to TP measured by standard vascular laboratory PPG equipment, the portable PPG test had good sensitivity (79%) and was highly specific (95%) to detect LEAD.25 (Test sensitivity is the ability to detect the presence of disease with few false negatives.67 Screening test sensitivity should be at least 70% to 80%.68 Specificity is the ability of a test to correctly identify the absence of a condition with few false positives, and a high specificity is needed for screening tests.67) Therefore, the portable PPG provides a good alternative to test for LEAD when ABI results are inconclusive, elevated, or not measurable.

TP limitations. According to Carter,37 TP provides an indirect assessment of blood flow in the toes and does not specifically show where a stenosis or obstruction is located. Also, TPs might not detect occlusions in the toe tips because pressure is measured at the base of the toes,25,37 Vasoconstriction of the digital arteries from coldness can affect TP, so it is important to keep the room temperature at a minimum of 21° to 23° ± 1° C (68° to 75° F) during the tests.37,38,70,71

Advantages of the Portable PPG

Tissue perfusion can be assessed with noninvasive tests such as laser Doppler, skin perfusion pressures (SPP), and transcutaneous oxygen measurement (TCOM), as well as PPG. The primary disadvantage of other noninvasive tests is cost of the equipment. For example, the portable equipment to measure TCOM and SPP costs five to eight times more than the portable PPG.32,71 Also, TCOM equipment requires calibration before each test. The portable PPG equipment has the advantage of being inexpensive, easy to use, and battery-operated, and it does not require routine recalibration, making it ideal to use in a variety of clinical settings including physician offices, home health, outpatient clinics, and long-term care facilities.25

Portable PPG technique. To accurately measure TP with a PPG, it is necessary to follow a standard procedure with attention to proper preparation and use of the equipment, along with appropriate preparation of the environment and patient (see Table 2). Clinicians also will benefit from education, training, and experience in the use of the portable PPG. Medical equipment suppliers of the portable PPG equipment provide educational and training materials. Also, if possible, it is helpful to the novice user of PPG to observe PPG testing in a vascular laboratory.

ABI and TBI can be performed using portable equipment in any clinical or home care setting to detect LEAD in an efficient and timely manner. ABI has been recommended as key to comprehensive lower extremity assessment and is viewed by several experts as an inexpensive and simple method to screen for LEAD, particularly in persons deemed at high risk.1,26,48,72

According to a prospective study to determine the average time for ABI measurement and barriers to performing the test in a primary care practice (PCP) by Pearson et al,73 the average time to complete an ABI in a PCP office by one provider (a physician) was 5 minutes. The physician reported that barriers to performing ABI were the extra time required

---

**Table 2. Summary of interobserver agreement (%) for ABI and TBI**

<table>
<thead>
<tr>
<th>Test</th>
<th>Interobserver Agreement (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABI</td>
<td>79</td>
</tr>
<tr>
<td>TBI</td>
<td>76</td>
</tr>
</tbody>
</table>

ABI: ankle-brachial index, TBI: transcutaneous blood index, PCP: primary care provider

---

**Figure 1. Schematic of ABI and TBI measurement**

1. **ABI Test Procedure:**
   - **Preparation:** Clean exposed skin, apply pressure cuff, deflate cuff to below systolic pressure.
   - **Measurement:** Record pressure at re-appearance of pulse waveform on PPG recorder.

2. **TBI Test Procedure:**
   - **Preparation:** Clean exposed skin, apply pressure cuff, deflate cuff to below systolic pressure.
   - **Measurement:** Record pressure at re-appearance of pulse waveform on PPG recorder.

---

**Figure 2. Ankle-brachial index (ABI) and transcutaneous blood index (TBI)**

ABI: ankle-brachial index, TBI: transcutaneous blood index, PPG: photoplethysmography, ABI: ankle-brachial index, TBI: transcutaneous blood index, PPG: photoplethysmography
to prepare and educate the patient about the test and results, but that ultimately performing the test in the PCP’s office saved time for the patient and the care provider by eliminating the additional time needed to refer to a vascular lab and wait for the results.

Relevance of assessment to outcomes. Although no specific studies relate early detection of LEAD to specific outcomes, experts recommend early preventive action before pain, ischemia, or wounds develop.\(^{22-29}\) Early detection of LEAD is necessary so interventions can be implemented to control modifiable risk factors through tobacco cessation, exercise, weight, glucose/HgA1c, hyperlipidemia, and hypertension.\(^{25,43,46,74}\) Early diagnosis provides an opportunity to educate patients about the symptoms and complications of LEAD and the importance of proper footwear and nail care and of promptly reporting any lower extremity wound to a healthcare provider.\(^{25,26}\) If the ABI/TBI are inconclusive, referral to a vascular laboratory is warranted for further testing (eg, duplex ultrasound, magnetic resonance imaging, computed tomography). If the ABI/TBI indicate LEAD, the patient should be referred to a vascular specialist or surgeon to evaluate the need for other therapies, such as medications, exercise programs, surgical intervention, or other adjunctive treatment.

Conclusion

Up to approximately 50% of all patients with LEAD are undiagnosed, which can result in unnecessary amputations in particularly high-risk groups such as patients with DM. Delaying referrals for vascular tests until patients with LEAD experience symptoms is problematic because individuals with asymptomatic as well as symptomatic LEAD are at the same risk for ischemia, pain, impaired quality of life, amputations, and increased mortality.\(^{25,59}\)

Portable PPG TP measures have been found to have a high level of agreement (good sensitivity and a high specificity) with vascular laboratory PPG tests to detect LEAD.\(^{22}\) Healthcare providers can use this inexpensive and easy-to-perform test in a variety of clinical settings to detect LEAD in a timely manner when the ABI cannot be relied on due to calcified arteries (ie, elevated ABI) and/or cannot be measured. Implementing TP measures using portable PPG to assess high-risk individuals such as patients with DM and elevated ABIs potentially can have a major impact on early identification of LEAD, so evidence-based prevention or therapeutic interventions can be implemented to prevent or reduce the negative sequelae of ischemia, including wounds and amputations.

References

29. Collins T, Suarez-Almazor M, Peterson N. An absent pulse is not sensitive for the early detection of peripheral arterial disease. Fam Med. 2006;38:38–42.

www.o-wm.com

OSTOMY WOUND MANAGEMENT     43

NOVEMBER 2011
**FEATURE**


35. Springer M, Fassotte C, Verhaeghe R. The ankle-brachial pressure index and a standardized questionnaire are easy and useful tools to detect peripheral arterial disease in non-claudicating patients at high risk. *Intern Angiol*. 2007;26:239–244.


