Redesigning Ankle-brachial Index Calculation For Better Wound Care: Research Shows The Way

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Abstract: Lower extremity wounds associated with peripheral arterial disease (PAD) and diabetes carry substantial risks of morbidity, amputation and health-care burden. Although clinical guidelines recommend the ankle-brachial index (ABI) as part of a comprehensive vascular assessment, its diagnostic accuracy is limited in patients with medial arterial calcification, commonly seen in diabetes, chronic kidney disease and advanced age. These limitations may lead to falsely normal ABI values and delayed recognition of PAD. The objective of this study was to compare standard ABI calculation with an angiosome-based ABI approach that accounts for the specific arterial supply of the wound's anatomical territory, and to determine whether this improves the accuracy and clinical relevance of ABI vascular assessment in patients with lower limb wounds. The findings support integrating angiosome-based ABI assessment into routine vascular evaluation of foot wounds.

Key words: *Lower limb wounds, diabetes, peripheral artery disease (PAD), ankle-brachial index (ABI), angiosome-based ABI, vascular assessment, limb salvage*

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Wounds represent a major public health issue with significant impacts on individuals, the environment, and health-care systems.[1-3] Wounds associated with peripheral arterial disease (PAD) and diabetes are a source of major suffering and financial burden for the patient and place a considerable burden on the patient's family, health-care providers and facilities, and society in general.[4,5] Previous reports have emphasized the synergistic effects of diabetes and PAD on amputation risk.[6-8] Patients diagnosed with both PAD and diabetes have been shown to be 7 to 15 times more likely to experience major amputation following the development of an ulcer, as compared with those without diabetes.[9,10]

Due to its numerous potential impacts on patients and its socioeconomic burden, PAD demands a responsive approach to ensure early detection.[11-13] Chronic limb-threatening ischemia (CLTI) represents the end stage of PAD and is a problem of growing prevalence, increasing health-care costs around the globe, and is associated with mortality, amputation and impaired quality of life.[12] According to the Global Vascular Guidelines on the Management of Chronic Limb-threatening Ischemia, all patients with suspected CLTI should be referred urgently to a vascular specialist.[12,14] According to Frykberg and Banks (2015), understanding and addressing the challenges inherent in the treatment of any kind of chronic wounds will lead to a better clinical outcome, resulting in improved patient quality of life and reduced health-care costs.[15]

The main recommendations for managing wounds in the lower limbs and feet have focused on two primary objectives: 1) determining if there is adequate blood flow to heal the wound and 2) assessing for signs and symptoms of peripheral arterial disease (PAD).[16,17] Multiple health-care specialists are involved in the management of PAD and CLTI, yet lack of public awareness and the frequent failure to make an early diagnosis continue to be significant obstacles to effective treatment.[12] According to the existing literature, non-invasive instruments are available in clinical services to assess arterial vascularization. The arteriobrachial index (ABI), arterial waveforms, toe pressure, and transcutaneous oximetry are the most widely recognized. Other vascular examinations, such as Doppler ultrasound, computed tomography, angiography (CT angiography) and arteriographic resonance imaging (ART), are used for a more anatomical descriptive evaluation of the arterial tree but primarily in the vascular laboratory, as is contrast angiography, which is also an invasive procedure.[18,19] The chapter on Prevention and Management of Peripheral Arterial Ulcers in Wounds Canada's *Best Practice Recommendations For Skin Health And Wound Management 2025* provides a guide to these non-invasive tests.[17]

Current clinical guidelines recommend performing a comprehensive vascular assessment of lower limbs with the ABI in patients with a lower limb wound.[4,5,11,17] A literature review by Dachun et al. (2010) acknowledges a high level of specificity for PAD (83.3–99.00%) for an ABI ≤ 0.90 in cases of more than 50% arterial stenosis in the lower limbs, but sensitivity levels of 15–79% for ABI > 0.90, with sensitivity being lower in the elderly and those with diabetes.[17] Variations in values may also stem from a lack of measurement standards and the different methods used in calculating the index.[21,22] Furthermore, the clinician's lack of experience, the type of Doppler device used and the technique for taking pressure measurements (with or without prior rest, head elevated or not, cuff size appropriate for limb circumference) are all parameters that can explain fluctuations in the data. Other major barriers to the use of ABI measurements are the availability of Doppler equipment, the time required to perform the examination and adequate training[23] and the ABI calculations themselves. A few studies already confirm many other methods for ABI calculations.[21,24-29] The most significant limitation of ABI is the potential incompressibility of calcified distal arteries in individuals with diabetes.[17,30,31]

This study is based on secondary data from a larger study with three other non-invasive instruments to detect PAD as Doppler arterial waveforms, toe pressure by plethysmography (manual) and laser.[32] These various criterion measurements are recognized in literature as theoretically competent for measuring arterial vascularization in the lower limbs to detect PAD. To ensure their convergence in the clinical trial, a table of their respective correlations was compiled during the study (Table 1).

Table 1: Correlations of vascular instrument

	Posterior tibialis monophasic waveforms	Dorsalis pedis monophasic waveforms	ABI < 0,5 and > 1,3	Manual TBP < 30 mmHg, ≥100mmHg	Laser TBP < 30 mmHg, ≥100mmHg
Posterior tibialis (PT) monophasic waveforms < 30 mmHg, ≥100mmHg	—	0,629**	0,328**	-0,223**	-0,101
Dorsalis pedis (DP) monophasic waveforms < 30 mmHg, ≥100mmHg	0,629**	—	0,377**	-0,304**	-0,195**
ABI < 0,5 and > 1,3	0,328**	0,377**	—	0,075	-0,049
Manual TBP	-0,223**	-0,304**	0,075	—	0,644**
Laser TBP	-0,101	-0,195**	-0,049	0,644**	—
*Pearson's R type correlation, ** p < 0.01					

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Contrary to expectations and the findings of the exhaustive literature review, negative correlation coefficients emerged, indicating a lack of convergence among the criterion measurements to explain PAD in the lower limb.[32] A negative correlation between two variables indicates that the values of one variable tend to increase when those of the other decrease. More specifically, this means that when monophasic dorsalis pedis artery wave measurement shows PAD, manual pressure measurement might show normal arterial vascularization.

Furthermore, we observed that the ABI values do not correlate with the toe pressure values. This could indicate that these two instruments measure two different things. However, the validity of ABI is known to be suboptimal in the presence of medial wall calcification of the main arteries, especially in the population with diabetes.[5,30,33] Moreover, noncompressible arteries may affect the ABI by providing falsely elevated or normal values in patients with diabetes, chronic renal insufficiency, or advanced age,[12,14] within conclusive, distorted results, or potentially overestimating the actual vascular flow. Inconclusive, distorted results and potentially overestimation of the actual vascular flow is often seen in individuals with diabetes,[12,14, 34] a population peculiarly affected by PAD.[35-37]

These results have raised significant questions about the validity of the results and interpretation for the ABI, its calculation method and the consideration of the foot's angiosomes. Angiosomes must be considered for all these non-invasive tests; otherwise, the interpretation of the vascular evaluation could be distorted.[38-40] An angiosome is a three-dimensional block of anatomical tissue supplied by a specific artery. The angiosome concept has gained popularity as an approach to improving limb recovery, in which target vessels for revascularization are chosen based on the angiosome containing the wound.[18] Although arterial connections exist between angiosomes, the angiosome theory posits that superior outcomes can be achieved by revascularizing the vessel that directly supplies an angiosome around tissue loss, rather than relying on indirect flow from arteries supplying adjacent angiosomes.[41] Neville's study retrospectively examined 52 incurable wounds in patients who had undergone bypass surgery and found that indirectly revascularized wounds were amputated in 38% of cases, compared to 9% of cases where the angiosome containing the wound was directly revascularized. Figure 1 shows the foot's angiosomes.

However, we know that ABI is widely used in our health-care organizations, so it becomes essential to optimize its measurement and interpretation. This study aims to highlight differences in ABI calculations and interpretations based on wound location and the foot's angiosome, enabling safe interpretation of results in the presence of PAD or CLTI. Ultimately, this study would help clinicians select the most appropriate ABI result for the clinical decision regarding the wound.

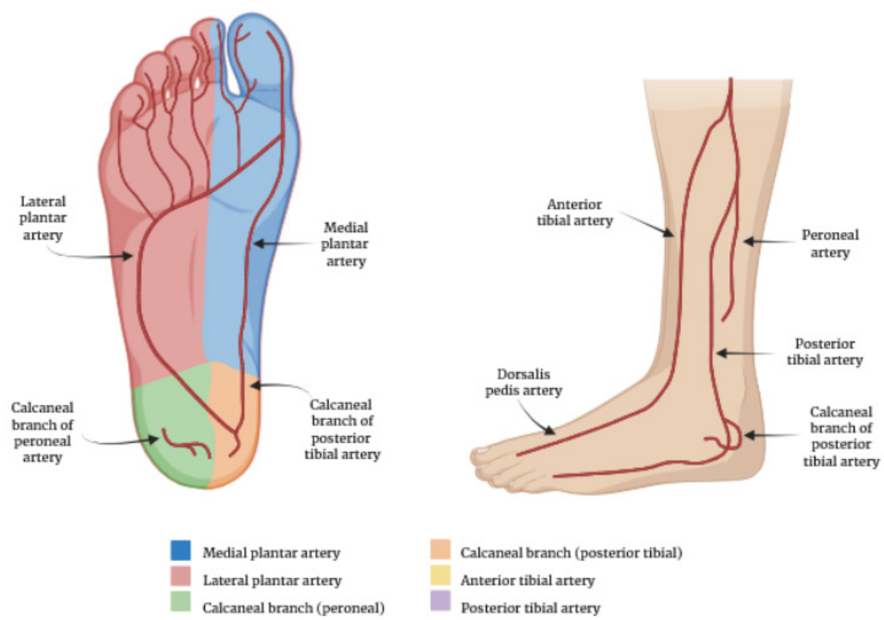

Figure 1: Anatomical distribution of the angiosomes of the foot and lower leg
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Methods

For this secondary analysis of a prospective population study from a doctoral research,[33] 108 ambulatory patients aged over 18 years and having at least one lower limb wound were recruited between May and August 2017 by convenience sampling technique at the Complex Wound Care Clinic, a Canadian university-affiliated regional hospital clinic. Institutional and University Ethics Board approvals (CER-17-235-10.02) were obtained for this study. According to the study protocol, written informed consent was obtained and documented from every patient retained. Patients were included if they presented with any kinds of lower limb wounds without regard to any diagnosis of chronic kidney disease, diabetes, PAD or CLTI. Exclusion criteria were having any condition preventing the ability to give proper consent and having received previous hyperbaric oxygen therapy.

Devices used for systolic blood pressure included a Welch Allyn sphygmomanometer with an adult cuff for arms with a circumference between 25 cm and 34 cm, or a large adult cuff for arms with a circumference greater than 34 cm up to a maximum of 38 cm. For ABI values, Huntleigh Doppler DMX Digital Doppler with Waveform (Arjo Inc., Addison IL) was used with a 8mHZ probe (See Figure 2). ABI values were obtained for every dorsal pedis (DP) and posterior tibial artery (PTA) of both feet using the same manual sphygmomanometer.

Figure 2: Posterior tibial artery (PTA) and Dorsal pedis (DP) systolic blood pressure. Photos used with permission of Maryse Beaumier.

For this study, the reference values for ABI were the results of a literature review. Articles in French and English were identified in the MEDLINE, Cochrane and Embase databases, without restriction to publication year. The keywords *ankle-brachial index (ABI), peripheral arterial disease (PAD), peripheral vascular disease, arterial occlusive disease, lower extremity* and *leg* were used for articles concerning the measurement of the ankle-brachial index. This search strategy yielded 568 articles on the ABI, 154 after title and abstract selection, and finally, 67 were deemed pertinent to respond to the research question. After analysis of the articles with Standards for the Reporting of Diagnostic Accuracy Studies (STARD), the reference's value for ABI for the presence of a severe PAD was determined to be smaller than 0.5 and over 1.3 (33).

A case study approach was used for this study.[42] The case study as a research method is appropriate for describing, explaining, predicting and controlling processes inherent in various phenomena, both individual and collective.[43,44] 'Explanation' aims to shed light on why things occur; 'prediction' seeks to establish, in the short and long term, what results will occur[42] and 'description' answers the questions who, what, when and how.[45]

In this study, the first ABI calculation method was performed according to Wounds Canada standards, by dividing the highest pressure between the two arteries in each foot (the dorsalis pedis and posterior tibial arteries) by the highest pressure between the two brachial arteries. The nurse performed all calculations at the time of measurement. The results were validated by a second evaluator before data compilation. The second method, ABI calculations and interpretations in the case studies, was with the choice of systolic pressure of one of the arteries of the foot, DP or PTA, which was made by considering which of the arteries best represented the location of the wound on the foot while respecting its angiosome. The research assistants used a programmed Excel chart to include many ABI methods calculations to compare at a subsequent time with the location of the wound on the corresponding photo (See Table 2).

Table 2: Example of an Excel chart illustrating different methods for calculating the ABI.

Arteries	Systolic blood pressure	Brachial Right arm	Brachial left arm	Mean right and left arms	Location of the wound
Monophasic or not	TB	135	132	133.5	
Right PTA	70	0.52	0.53	0.52	
Right DP	40	0.30	0.30	0.30	
Left PTA	128	0.95	0.97	0.96	
Left DP	85	0.63	0.64	0.64	*Photos used with permission of Maryse Beaumier.*

Legend: posterior tibialis arteries (PTA), dorsal pedis (DP), Toe blood pressure (TB)

Table 3: Baseline characteristics of included patients

Variables	All patients n[%]
Women, n[%]	44[41]
Men, n[%]	64[59]
Characteristics	
Age, median	70.5[59-78]
Smokers or past smokers	67[62]
Diabetes, n[%]	59[55]
Chronic kidney disease, n[%]	19[18]
Amputated, n[%]	15[14]

Two case studies	Standard ABI calculation using value of PTA	Angiosome ABI calculation using value of DPA in respect of wound location and its angiosome
	0.83 Mild PAD	0.38 Severe PAD
	0.77 Mild PAD	0.50 Moderate to severe PAD

Figure 3: Two case studies

Photos used with permission of Maryse Beaumier.

Results

One hundred and eight (108) patients were recruited and documented on a case study form, totalling 295 lower limb wounds (captured in photos), representing 77 patients with a total of 143 wounds on the feet. Regarding the criteria measurements, 91.6% of patients have been assessed using the ABI measurement. In this study, using the angiosome concept, another ABI calculation was performed based on the systolic pressure of the specific artery supplying the wound location. All patients' and group-specific characteristics are summarized in Table 3.

The results from angiosome ABI calculation differed from the standard ABI calculation. In these case studies, 48% standard ABI calculations were representative of the artery irrigating the wound bed and 40% of them were not. Meanwhile, 12% had uncompressible arteries. Also, Doppler waveform sounds hold value in assisting ABI in the prediction of potential insufficient arterial blood supply. Toe blood pressure results were most useful in peripheral arteries with calcification, where ABI results are inconclusive.

Based on the angiosome concept, the specific angiosome ABI calculation was also found to have lower indexes than the standard ABI calculation, representing the closest reality of arterial vascularization to the wound, thus allowing for the best response to the first recommendation in order to properly assess it before making a clinical decision for wound care (See Figure 3). Therefore, taking the highest or lowest systolic pressure is no longer relevant to this approach, thus simplifying the harmonization of the method for clinicians.

Additionally, this approach emphasizes the significance of assessing systolic foot pressure between the dorsalis pedis (DP) and the posterior tibial artery (PTA) in order to conduct distinct calculations for each artery, thus enhancing a best PAD detection using the ABI.

Discussion

In patients with diabetes, peripheral artery disease (PAD) may go undiagnosed until they experience severe tissue loss.[46,47] It is crucial to address underlying PAD when caring for patients with lower extremity and foot ulcers.[6] Insufficient local vascular supply can lead to poor tissue oxygenation, promoting microbial growth, increasing the risk of infection and decreasing the likelihood of wound healing.[48] An incorrect assessment of the arterial vascularization of a foot wound can have serious consequences, leading to ineffective treatment, delayed or failed healing, amputations, a diminished quality of life and even premature death. An analysis of results from previous doctoral studies indicated that non-invasive instruments for assessing PAD do not always correlate well, and their effectiveness can vary based on the wound location and degree of arterial calcification.[32]

This variation can be explained by the concept of angiosomes, which suggests that each area of the foot has its own arterial blood supply and specific vascular territories.[39,40] Understanding the angiosomes of the foot and the interaction of their originating arteries is clinically beneficial, especially in the presence of PAD. This knowledge can aid in diagnosing PAD by allowing instruments to target arteries based on the location of foot wounds. The standard ankle-brachial index (ABI) calculation, which involves dividing the highest pressure measured between the two arteries in each foot (the dorsalis pedis and posterior tibial arteries) by the highest pressure recorded between the two brachial arteries,[49] may be inadequate when compared to a specific angiosome ABI calculation. This is particularly true when assessing arterial blood supply in cases of severe PAD and CLTI.

All the non-invasive instruments results help in the clinical decision for treatment of the wound. This clinical decision for selecting appropriate dressings differs significantly in cases of severe PAD and CLTI.[49,50] As stated in guidelines, “In arterial ulcers with sufficient arterial inflow to support healing, use a dressing that will maintain a moist wound-healing environment (Level IIA). Dry gangrene or eschar is best left dry until revascularization is successful (Level IIA)”.[13]

Conclusion

Current clinical guidelines recommend conducting a comprehensive vascular assessment of the lower limbs, which includes measuring the ankle-brachial index (ABI) for patients with lower limb wounds.[11,12,14] However, the validity of this test can be suboptimal in cases of medial wall calcification in the main arteries, particularly among people with diabetes.[4,30,49,50] This limitation may lead to falsely elevated or normal ABI values in patients with diabetes, chronic kidney disease, or those who are older.[12,14] Individuals with diabetes often experience inconclusive and distorted results, which can result in an overestimation of actual vascular flow.[12,14,34,50,51] This population is particularly susceptible to PAD.[35-37]

This study aimed to examine differences in ABI calculations and interpretations based on wound location and the foot's angiosomes. By doing so, we hope to improve screening performance and enable a safe interpretation of results in patients with PAD or critical limb-threatening ischemia (CLTI). Previous case studies have demonstrated a significant difference between standard ABI calculations with and without considering angiosomes, showing a 40% improvement in PAD assessment when wound location is considered. To address the issue of false-negative results, clinical guidelines for managing PAD and CLTI recommend supplementing the ABI with either the absolute systolic toe pressure (TP) or the toe-brachial index (TBI) to enhance assessment accuracy. Both of these methods have been shown to be more sensitive in diagnosing PAD, and the calculation index is not necessary to avoid calculation errors.[51] Furthermore, as previously demonstrated, measuring toe pressure using photoplethysmography (PPG) has a strong correlation (r=0.92, p < 0.001) with laser Doppler flowmetry (LDF).52 This makes manual toe pressure measurement an accessible first-line screening tool to complement ABI results.

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