Research Square

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Diagnostic accuracy of ankle-brachial index versus pulse wave index measurements in the diagnosis of peripheral arterial disease in diabetic patients: A retrospective record-based study

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Abstract

Background:

Peripheral artery disease (PAD), a macrovascular consequence that raises the risk of lower-extremity amputation and mortality, is common in patients with diabetes. Due to non-compressible vessels, the Ankle Brachial Index (ABI), which is commonly used to evaluate PAD, produces false-negative results. The purpose of this study was to determine whether the pulse wave index (PWI) provides better diagnostic accuracy than ABI for the early detection of PAD in diabetics.

Methods:

Electronic file system registrations from a vascular surgery outpatient clinic at As-Salam Hospital in Port Said, Egypt, were used in a retrospective record-based investigation. Patient demographics, glycemic control (HbA1c), and current comorbidities were all included in the data of 184 diabetic patients over 40. The records showed PAD at ABI < 0.9 and PWI > 300.

Results:

The average age of 184 participants was 60.93 ± 9.68 years. By PWI and ABI, the prevalence of PAD was 25% and 20%, respectively. With an AUC of 0.805 (95% CI: 0.712–0.898, p = 0.002), ROC curve analysis showed that PWI outperformed ABI in terms of diagnostic performance (AUC: 0.663; 95% CI: 0.543–0.783, P < 0.001). PWI showed a strong negative predictive value (93%) and good sensitivity (88.9%) at an ideal cutoff > 156. ABI (< 0.895), on the other hand, had low sensitivity (41.7%) but good specificity (95.9%).

Conclusion:

The pulse wave index performs better than the ankle-brachial index in terms of sensitivity and diagnostic efficacy when it comes to detecting peripheral arterial disease in high-risk diabetic patients. Future research should evaluate the long-term feasibility of employing PWI as the primary screening method to reduce PAD-related problems.

Introduction

Because it raises the risk of amputation and mortality, peripheral arterial disease (PAD) is a prevalent cardiovascular condition linked to reduced quality of life, walking ability, and functional status [1].

For individuals 65 years of age or older with cardiovascular risk factors, the European Society of Cardiology (ESC) suggests screening for PAD using ABI or TBI; for patients with diabetes or chronic kidney disease (CKD), the Toe-Brachial Index (TBI) is recommended [2].

A thorough vascular examination and inspection of the legs and feet should be routinely carried out for patients at increased risk of PAD, according to the American Heart Association (AHA) 2024. This is

especially important for diabetic patients under 50 who have one additional risk factor for atherosclerosis or for those between the ages of 50 and 64 who have risk factors for atherosclerosis (e.g., diabetes, history of smoking, dyslipidemia, hypertension, CKD, or family history of PAD). Using the resting ABI, with or without ankle pulse volume recordings (PVR) and/or Doppler waveforms, is recommended to confirm the diagnosis in individuals with a history or physical examination results suggestive of PAD. [1].

There are very few publications on the prevalence of PAD in the Arab world; it was estimated at 32.2% in a study in KSA among diabetic patients [3], 22% in Nigerians with type 2 diabetes [4], and 33.5% in an Egyptian diabetic patient's study [5].

A meta-analysis included 155 articles; the global prevalence of PAD was 19%, which was more prevalent in developing than in developed settings (PAD: 24% vs. 10%) [6].

The ankle-brachial index (ABI) is assessed by utilizing non-invasive Doppler ultrasound to measure blood pressure at rest and/or after exertion; a value at rest below 0.9 is deemed confirmation of the diagnosis of PAD. To validate PAD in the context of media sclerosis (ABI > 1.3), pulse curve analysis, digital artery pulse oscillography, and toe pressure measurement with TBI (toe-brachial index) determination are critical [7].

There is an increased interest in PAD diagnosis by utilizing arterial pulse waveform analysis. PAD generates occlusions in the arteries, which in turn modify pulse wave propagation and reflection properties in the arteries subject to PAD, consequently resulting in the variations in the morphology of arterial BP and blood flow waveforms [8].

A pneumoplethysmographic test called the PVR evaluation is performed to identify changes in segmental volume. Pneumatic cuffs are inflated to a standard pressure of 65 mmHg and positioned at various points along an extremity. The lack of the dicrotic notch on the pulse wave is the first indication of PAD in PVR testing, and the inflating pressure enables venous outflow blockage and an isolated assessment of the arterial pressure waveform. The main advantage of pulse volume recording (PVR) is that the evaluation is significantly less likely to be hampered by arterial calcifications. [9].

PVW demonstrated the highest sensitivity (81.8%) for identifying PAD in diabetic patients in a prior study comparing various methods (diagnostic performance of plethysmographic- and Doppler-derived ankle brachial index, toe brachial index, and pulse volume wave analysis). This was followed by ABI_{DOP} (72.7%) and ABI_{PLE} (20%). All devices, however, demonstrated outstanding specificity in identifying PAD. [10].

So, this study aims to compare PWI versus ABI for accurate diagnosis of PAD among diabetic patients in Port Said Governorate, Egypt.

Subjects and Methods

Type of the study:

A retrospective record-based study depending on data registrations in the electronic file system of diabetic patients in the vascular surgery outpatient clinic at As-Salam Hospital, affiliated with the Health Care Authority, Port Said Governorate, Egypt.

Sampling:

Convenient sample for all diabetic patients attending by referral from primary care units for screening in the vascular surgery outpatient clinic in As-Salam Hospital, affiliated with the Health Care Authority, Port Said Governorate, Egypt.

Sample size

According to the following equation

DIAGNOSTIC ACCURACY

$$n = \left[\frac{Z_{\alpha/2}}{E}\right]^2 * \frac{S_n(1 - S_n)}{(P)}$$

$$n = \left[\frac{Z_{\alpha/2}}{E}\right]^2 * \frac{S_p(1 - S_p)}{(1 - P)}$$

Where

n= sample size
Z α/2 = 1.96 (The critical value that divides the central 95% of the Z distribution from the 5% in the tail)
p = Prevalence/proportion of disease
Sp= Specificity
Sn= Sensitivity
E = the margin of error (=width of confidence interval)

As P = Prevalence in a recent study (Ascencio AIP et al., 2024) determined as 11.2%

And specificity of ABI is about 88%.

E = 5%

The result of the sample size calculation is that about 183 diabetic patients attending the outpatient clinic for screening of PAD had been included in the study.

Study period:

3 months for collection of data and analysis of results.

Study setting:

vascular surgery outpatient clinic at As-Salam Hospital Affiliated with the Health Care Authority Port Said

Study population:

Inclusion criteria:

Diabetic Patients (Males and Females) aged ≥ 40 years.

Exclusion criteria:

- Patients who had done vascular procedures for the ligation of arteries in the upper limbs.
- Patients with arteriovenous fistulas for dialysis

Study method:

After approval of data collection from the authority, information about history and comorbidities such as hypertension, dyslipidemia, or chronic renal disease and clinical examination with assessment of previous amputation.

The examination's findings will be recorded. A semi-automatic four-point oscillometric instrument (Ang E, SOT Medical Systems, Maria Rain, Austria) was used to measure ABI, PWI, and toe pressure index (TPI) in order to confirm results in suspected cases.

Oscillometric ABI measurement

An AngE Pro8 (SOT Medical Systems, Maria Rain, Austria) with software version 1.06.15 was used to take the measurements. The pulse waves were obtained at various cuff pressures using the Gesenius-Keller method. The maximal amplitude was used to calculate the mean arterial pressure, and oscillometric ABI (oABI) was defined as the ratio of the amplitude between the upper and lower extremities.

Following a 10-minute rest and while in the supine position, the cuffs were positioned in accordance with the manufacturer's instructions. PAD was detected at an ABI < 0.9.

The Pulse Wave Index (PWI) is the second parameter. PWI was computed by dividing the maximal pulse amplitude obtained at the lower leg (left or right) by the maximal amplitude of the upper extremities (left or right) and then multiplying the result by the pulse wave's peak time. PWI > 300 indicated PAD.

Statistical Analysis

SPSS version 25 was used to analyze the data. The mean ± standard deviation (SD) was used to depict variables that were normally distributed. Frequencies and percentages were used to display categorical variables.

Receiver operating characteristic (ROC) curve analysis was used to assess the diagnostic performance of the ankle-brachial index (ABI), pulse wave index (PWI), and their combined model. To evaluate discriminatory capacity, the area under the ROC curve (AUC) with 95% confidence intervals (CI) was computed. The Youden index, which finds the threshold that maximizes the combined sensitivity and specificity, was used to identify the ideal cutoff values for ABI and PWI.

For every cutoff point, the following metrics were computed: sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and total diagnostic accuracy. AUC values were used to

compare the diagnostic performance of ABI, PWI, and their combined model. Statistical significance was defined as a two-sided p-value of less than 0.05.

Results

Characteristics of the Research Population

The study comprised 184 individuals in total. The distribution of sexes was almost equal, and the mean age was 60.93 ± 9.68 years. BMI mean: 27.32 ± 7.86 kg/m²

Laboratory Characteristics

The mean glycated hemoglobin (HbA1c) level was 7.65 ± 2.07%, indicating suboptimal glycemic control in the study population. The average total cholesterol level was 196.37 ± 41.05 mg/dL, while mean triglyceride levels were 188.75 ± 74.71 mg/dL. 1.24 ± 0.59 mg/dL was the mean serum creatinine.

Diabetes-Related Complications

Among the study participants, neuropathy was the most frequent complication (39.1%), followed by cardiovascular disease and retinopathy (30.4% & 25.5%, respectively). Nephropathy was observed in 18.5% of cases. A history of major amputation was present in 7.1% of patients. **(**Table 1**).**

Peripheral Arterial Disease Assessment

The mean ankle–brachial index (ABI) values were 1.08 ± 0.19 for the left side and 1.06 ± 0.16 for the right side. Mean pulse wave index (PWI) values were 228.15 ± 135.32 on the left and 219.70 ± 129.42 on the right. The inverse relationship between ABI and PWI supports the concept that as arterial obstruction and stiffness increase, ABI decreases while PWI rises. The marked elevation of PWI in PAD patients highlights its potential value as a sensitive marker for vascular impairment, suggesting PWI may surpass ABI in accuracy for populations prone to arterial calcification, which often yields falsely elevated ABI results **(**Table 2**).**

Prevalence of PAD

A quarter of patients demonstrated pathological findings consistent with peripheral arterial disease on PWI, whereas only 20% were identified using ABI **(**Fig. 1**).**

Diagnostic Performance of ABI and PWI

ABI's moderate discriminatory capacity was shown by ROC curve analysis, with an AUC of 0.663 (95% CI: 0.543–0.783, $p < 0.001$). ABI demonstrated good specificity (95.9%) but low sensitivity (41.7%) with a cutoff value of < 0.895, suggesting that although ABI is useful in confirming diseases when positive, it is unable to identify a significant percentage of affected patients. Strong rule-in but poor screening performance were reflected in the total diagnosis accuracy of 85%. **(**Fig. 2a**).**

With an AUC of 0.805 (95% CI: 0.712–0.898, p = 0.002), PWI demonstrated higher diagnostic performance. PWI showed great sensitivity (88.9%) and a strong negative predictive value (93%) at a threshold value > 156, making it a dependable method for ruling out illness. But compared to ABI, its specificity was low (35.8%), suggesting a larger false-positive rate. **(**Fig. 2 **(b)).**

Combining ABI and PWI enhanced diagnostic balance, as evidenced by the AUC of 0.684 (95% CI: 0.572–0.796, p < 0.001). While keeping a respectable sensitivity of 38.9%, the combined method raised specificity to 97.9% and positive predictive value to 82.4%. This implies that combining the two indices improves diagnostic confidence, especially when verifying the existence of a disease. **(**Table 3**).**

Peripheral arterial disease was significantly predicted by both ABI and PWI. But compared to ABI, PWI was a better predictor. ABI had a lesser correlation with the occurrence of PAD than higher PWI values. This implies that in situations when ABI measures would be less accurate, PWI might be more helpful than ABI for detecting patients with PAD. **(**Table 4**).**

Discussion

In this study, we evaluated the diagnostic performance of ankle–brachial index (ABI), pulse wave index (PWI), and their combined model for detecting peripheral arterial disease (PAD) in a high-risk diabetic population characterized by suboptimal glycemic control and multiple vascular comorbidities. Our findings demonstrate: (1) moderate diagnostic performance of ABI with high specificity but low sensitivity; (2) superior discriminative ability of PWI with high sensitivity and negative predictive value; and (3) improved specificity and positive predictive value with the combined ABI–PWI model, although without improvement in overall AUC beyond PWI alone.

In our study, the mean HbA1c of 7.65% reflects suboptimal glycemic control, a well-established driver of endothelial dysfunction and accelerated atherosclerosis. Chronic hyperglycemia promotes oxidative stress, inflammation, and arterial stiffness, contributing to PAD development. The 25% prevalence of PAD findings in our cohort by PWI is consistent with reports showing PAD prevalence is 25% among diabetic patients depending on age and disease duration [11, 12].

Our finding that ABI has high specificity, but limited sensitivity aligns with multiple systematic evaluations. Atherosclerosis-focused meta-analyses and diagnostic accuracy reviews report pooled ABI sensitivity for ≥ 50% arterial stenosis around 61%, with consistently high specificity (≈ 90%+), but performance falls in diabetic or calcified-vessel populations where noncompressible arteries can provide falsely normal or high ABI values [13, 14]. The American Heart Association scientific statement and subsequent reviews explicitly warn that ABI underestimates PAD in the presence of medial calcification and chronic kidney disease, recommending adjunct tests when ABI is borderline or inconsistent with symptoms [15, 16]. Herraiz-Adillo and colleagues' pooled analysis similarly reported that ABI sensitivity is moderate and variable by population characteristics, supporting our observed sensitivity of 41.7% in a high-risk diabetic group [12]. ABI remains a useful confirmatory test where an abnormal ABI is strong evidence of PAD, but in diabetes a normal ABI does not exclude disease and should prompt further noninvasive assessment if clinical suspicion exists.

Our PWI result (AUC 0.805, sensitivity 88.9%, NPV 93%) is concordant with multiple studies showing that waveform-based or oscillometric pulse-wave indices (including semi-automated devices that output a pulse-wave index or waveform classification) improve sensitivity relative to Doppler ABI, particularly in settings of arterial stiffness or calcification [17–19]. Diagnostic and device comparison trials (oscillometric ABI + waveform analysis vs Doppler ABI) report that adding pulse-wave or stiffness measures increases case detection and reduces false negatives in diabetic and elderly cohorts [17, 20]. PWV and other arterial stiffness markers also have robust evidence as early indicators of vascular disease and predictors of cardiovascular events, supporting the biological plausibility that PWI captures earlier or complementary pathology to ABI [21, 22].

Importantly, many waveform/PWI methods trade sensitivity for lower specificity (more false positives) because arterial stiffness reflects systemic vascular aging rather than focal occlusive disease. Our modest PWI specificity (35.8%) matches this pattern and aligns with prior device/oscillometric literature [17, 19].

The combined model in our study substantially raised specificity (97.9%) and PPV (82.4%) while sensitivity remained modest. This pattern (combined testing improving confirmation rather than overall discrimination) has been observed in the literature: guideline updates and diagnostic series recommend combining pressure ratios (ABI or toe-brachial index) with waveform/volume pulse analysis to improve diagnostic certainty when tests agree and to guide the need for imaging where tests conflict [15, 20]. Fendrik et al. specifically reported that oscillometric ABI plus estimated cf-PWV increased sensitivity of automated screening devices for PAD compared with oscillometric ABI alone, but the net effect on overall AUC can vary based on device algorithms and disease prevalence [18].

These findings encourage using PWI/waveform analysis for sensitive screening and relying on ABI (or imaging/toe pressures) for confirmation; concordant abnormalities substantially increase the likelihood of true disease.

Several recent studies and reviews emphasize the value of TBI when ABI may be falsely elevated due to medial calcinosis. Cleofort et al. and Singhania et al. reported higher sensitivities for TBI (≈ 70–82%) in diabetic cohorts versus ABI, confirming that toe pressures are less affected by calcification and often outperform ABI for detecting PAD in diabetics [20, 23]. Meta-anaylsis undermines ABI if noncompressible or equivocal; then TBI or waveform/PVR improves detection. Our findings that PWI detects more cases than ABI are consistent with this diagnostic pathway [24].

Differences across studies relate to populations (general vs. diabetic/CKD), reference standard (angiography, duplex ultrasound, clinical endpoint), device algorithms (oscillometric vs. photoplethysmographic waveform analysis), and cutoffs used. Meta-analyses that pool diverse populations show moderate ABI sensitivity overall but lower sensitivity in diabetes, while device studies show oscillometric waveform analysis and PWV measures can improve detection but require standardization [13, 17]. This heterogeneity explains why older general-population studies (Edinburgh

Artery Study) reported stronger ABI performance, whereas more recent diabetes-focused device studies show the limits of ABI and the value of waveform metrics [17, 25].

The multivariable analysis result that PWI is a stronger independent predictor of PAD than ABI aligns with increasing evidence that arterial stiffness (PWV) and waveform abnormalities predict cardiovascular events and may offer additive prognostic information beyond ABI and traditional risk scores [21, 22]. However, long-term prospective studies specifically linking PWI metrics to PAD outcomes (amputation, revascularization, limb events) are fewer; most PWV literature focuses on global cardiovascular risk, so further PAD-specific prognostic work is needed [26].

Conclusion

In this high-risk diabetic population, pulse wave velocity demonstrated superior diagnostic performance compared with ankle–brachial index for detecting peripheral arterial disease. ABI maintained high specificity but limited sensitivity, consistent with previous literature highlighting its limitations in calcified vessels. The combined ABI–PWI model improved diagnostic confirmation but did not surpass PWI alone in overall discrimination. These findings support incorporating arterial stiffness assessment into PAD screening strategies, particularly in diabetic patients where ABI may underestimate disease burden.

Study strengths and weaknesses

Strengths of our study include direct head-to-head comparison of ABI and PWI in a real-world diabetic cohort, ROC-based cutoffs, and multivariable modeling.

Limitations mirror those in the literature: cross-sectional design, lack of universal angiographic gold standard, single-center setting, and device-specific PWI algorithms that may reduce generalizability. In the future, we recommend prospective multicenter validation of PWI cutoffs, head-to-head comparisons of PWI vs TBI vs imaging, and assessment of PWI's prognostic value for limb- and cardiovascular outcomes.

Abbreviations

ABI
Ankle–Brachial Index
ABI_{DOP}
Doppler derived ankle brachial index
ABI_{PLE}
Plethysmography derived ankle brachial index
AUC
Area Under the Curve
cf-PWV

Carotid–Femoral Pulse Wave Velocity
CKD
Chronic Kidney Disease
HbA1c
Glycated Hemoglobin
KSA
Kingdom of Saudi Arabia
NPV
Negative Predictive Value
PAD
Peripheral Arterial Disease
PPV
Positive Predictive Value
PVR
Pulse Volume Recording
PWV
Pulse Wave Velocity
PWI
Pulse Wave Index
ROC
Receiver Operating Characteristic
TBI
Toe–Brachial Index
TPI
Toe Pressure Index

Declarations

Ethics approval and consent to participate: -

The study was conducted in accordance with the principles of the Declaration of Helsinki. Formal ethical approval was obtained from the Institutional Review Board (IRB) of Faculty of Medicine, Suez University. The committee's reference number is SUEZ – MED IRB 46.

The relevant authorities were contacted to obtain permission to conduct the study.

All data was confidential to the researcher and was published anonymously.

Consent for publication

All authors have read and agreed to the manuscript and publication.

Availability of data and materials

Data is available from the corresponding author upon request.

Competing interests

"The authors declare that they have no competing interests"

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Dual publication

the results/data/figures in this submission have not been previously published or are under consideration for publication elsewhere.

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Authors' contributions

AE and **TM** helped with the conceptualization.

ML and **AE** helped gather the data.

RF wrote the initial draft, the review, and the editing.

TM completed the data analysis, findings writing, and manuscript finalization.

ML helped oversee the work.

TM is the corresponding author.

Authorship

The corresponding author confirm that all authors have read the journal policies and is submitting their manuscript in accordance with those policies.

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Tables

Table 1
The study participants' baseline clinical, laboratory, and demographic characteristics

Characteristic	**Mean ± SD**
Age in years	60.93 ± 9.68
Gender n (%)	
Male	89 (48.4)
Female	95 (51.6)
BMI (kg/m²)	27.32 ± 7.86
Laboratory Characteristics	
HbA1c (%)	7.65 ± 2.07
Cholesterol total (mg/dL)	196.37 ± 41.05
Triglycerides (mg/dL)	188.75 ± 74.71
Serum Creatinine (mg/dL)	1.24 ± 0.59
Complications of diabetes in the study subjects	N (%)
Nephropathy	34 (18.5)
Neuropathy	72 (39.1)
Retinopathy	47 (25.5)
Cardiovascular Disease	56 (30.4)
History of Major Amputation	13 (7.1)

Table 2
PAD Diagnostic Measurements of the study subjects

Parameter	PAD Absent (n = 145)	PAD Present (n = 35)	Total (n = 180)	P value
Left ABI	1.10 ± 0.17	1.01 ± 0.23	1.08 ± 0.19	0.01*
Right ABI	1.07 ± 0.14	1.01 ± 0.21	1.06 ± 0.16	0.03*
Left PWI	190.34 ± 66.88	385.86 ± 214.76	228.15 ± 135.32	<0.001**
Right PWI	192.38 ± 72.78	333.63 ± 222.55	219.70 ± 129.42	<0.001**

Table 3
Diagnostic accuracy of ABI and PWI

Parameter	ABI	PWI	Combined ABI & PWI
Cutoff	0.895	> 156	ABI < 0.895 & PWI > 156
AUC	0.663	0.805	0.684
95% CI	0.543–0.783	0.712–0.898	0.572–0.796
Sensitivity (%)	41.7	88.9	38.9
Specificity (%)	95.9	35.8	97.9
PPV (%)	71.4	25.2	82.4
NPV (%)	87.1	93	86.8
Accuracy (%)	85	46.2	86.4
P value	<0.001**	0.002**	<0.001**

Table 4
Regression analysis of predictors of PAD

	B	CI	P value
ABI	**0.05**	**0.005–0.595**	**0.01***
PWI	1.01	1.008–1.018	<0.001**

Figures

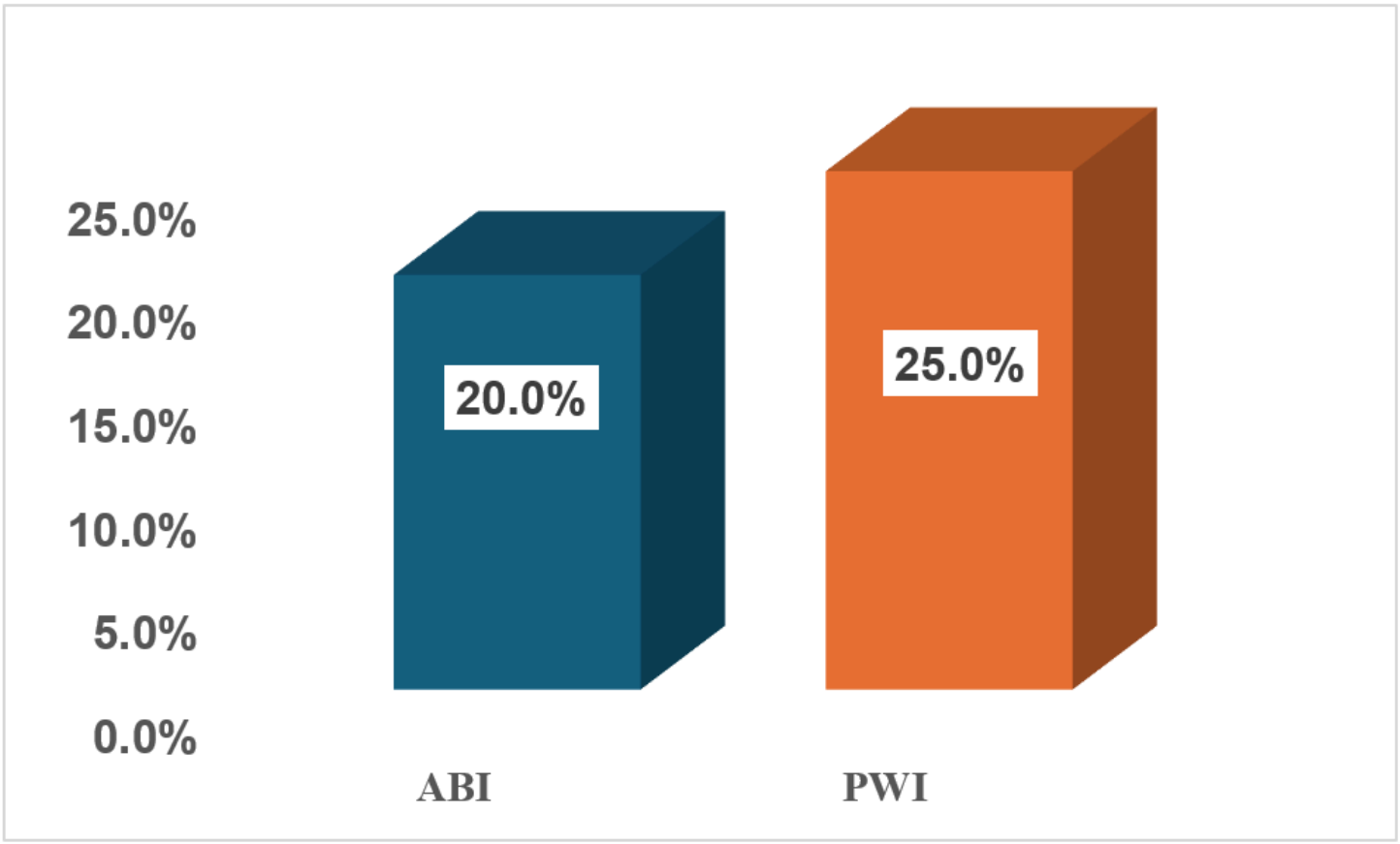


Figure 1

Prevalence of PAD among study population (N=184)

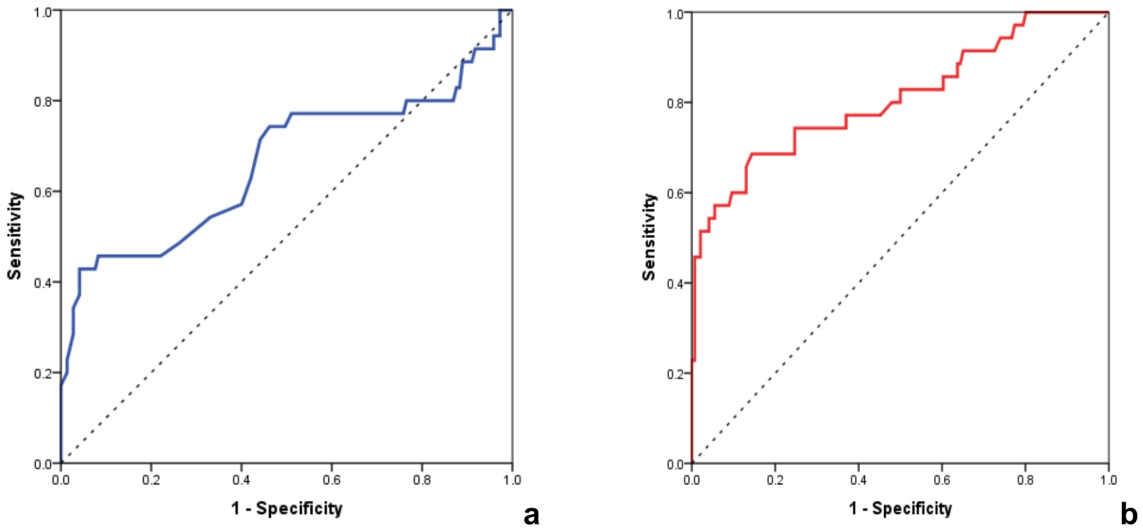


Figure 2

ROC curve of ABI (a) PWI (b)