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Original Article

Study of Correlation between Ankle Brachial Index and Arterial Doppler in Diabetic Foot Patients

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ABSTRACT

Background: Ankle–brachial index (ABI) and arterial Doppler ultrasonography are commonly used non-invasive modalities for vascular assessment in diabetic foot patients. The objectives were to evaluate the correlation between ankle–brachial index and arterial Doppler findings in patients with diabetic foot disease and to assess the utility of ABI as a screening tool for peripheral arterial disease. Methodology: This hospital-based observational cross-sectional study was conducted among 100 diabetic foot patients attending the Department of General Surgery at a tertiary care centre. Demographic details, duration and type of diabetes, comorbidities, ulcer characteristics, Wagner grading, and neuropathy status were recorded. ABI was measured using standard Doppler-assisted methodology, and lower limb arterial Doppler ultrasonography was performed to assess flow pattern, peak systolic velocity, and evidence of PAD. Results: Most patients had abnormal ABI values suggestive of peripheral arterial disease. Arterial Doppler demonstrated significant vascular abnormalities, predominantly biphasic and monophasic flow patterns. A significant correlation was observed between worsening ABI values and abnormal Doppler findings. Patients with lower ABI values had significantly higher prevalence of PAD on Doppler evaluation. ABI showed good diagnostic utility for prediction of PAD, with ROC analysis demonstrating clinically acceptable discriminative ability. Conclusion: ABI showed significant correlation with arterial Doppler findings in diabetic foot patients and may serve as an effective, inexpensive, and accessible screening tool for early detection of PAD. However, Doppler ultrasonography remains important for confirmation and detailed vascular assessment, particularly in patients with suspected arterial calcification.

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INTRODUCTION

Diabetes mellitus is a major global public health problem associated with significant vascular complications affecting both macrovascular and microvascular systems. Among these, diabetic foot disease remains one of the leading causes of hospitalization, morbidity, and non-traumatic lower limb amputation worldwide. Peripheral arterial disease (PAD), neuropathy, and infection collectively contribute to the development and progression of diabetic foot ulcers. Early recognition of vascular compromise is therefore essential for prevention of tissue loss and limb-threatening ischemia. [1,2]

PAD in diabetic patients is characterized by accelerated atherosclerosis, endothelial dysfunction, chronic inflammation, and medial arterial calcification. These pathological changes commonly involve infra-popliteal and distal vessels, resulting in reduced tissue perfusion and impaired wound healing. Diabetic patients frequently present with atypical or silent ischemia due to associated neuropathy, leading to delayed diagnosis and increased risk of ulceration, gangrene, and amputation. [3,4]

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Accurate assessment of lower limb perfusion is fundamental in the evaluation of diabetic foot disease. Clinical examination alone is often insufficient because it may not reliably reflect the severity of arterial compromise. Consequently, non-invasive vascular assessment tools such as ankle–brachial index (ABI) and arterial Doppler ultrasonography have become integral components of diabetic foot evaluation. [5]

The ankle–brachial index is a simple, inexpensive, bedside investigation that compares systolic blood pressure at the ankle with brachial artery pressure. An ABI value below 0.9 is generally considered suggestive of PAD. The test is widely used because of its accessibility and ease of performance. However, diabetic patients often develop medial arterial calcification causing arterial incompressibility and falsely elevated ABI values, thereby reducing diagnostic accuracy in certain cases. [6,7] Arterial Doppler ultrasonography provides additional anatomical and hemodynamic information regarding lower limb circulation. It evaluates arterial patency, waveform characteristics, flow velocities, stenosis, and occlusion. Doppler assessment can identify biphasic or monophasic flow patterns suggestive of significant vascular disease even when ABI values appear falsely normal. Therefore, arterial Doppler is considered an important adjunctive investigation in diabetic patients with suspected PAD. [8]

Several studies have demonstrated that combined use of ABI and Doppler ultrasonography improves detection of PAD in diabetic foot patients. Correlating ABI values with Doppler findings may help determine the reliability of ABI as a screening modality and guide decisions regarding further vascular evaluation and management. Early diagnosis of PAD allows timely institution of revascularization, wound care, infection control, and limb salvage strategies. [9]

Despite increasing prevalence of diabetic foot disease in developing countries, data regarding correlation between ABI and arterial Doppler findings in Indian diabetic foot patients remain limited. The present study was therefore undertaken to evaluate the association between ABI and arterial Doppler findings in patients with diabetic foot disease attending a tertiary care centre.

MATERIAL AND METHODOLOGY

This hospital-based observational cross-sectional study was conducted in the Department of General Surgery in a tertiary care centre after obtaining approval from the Institutional Ethics Committee. The total duration of the study was 18 months.

Adult patients aged between 18 and 70 years with confirmed diabetes mellitus (Type 1 or Type 2) presenting with diabetic foot pathology, including ulcers, gangrene, cellulitis, abscess, necrotizing fasciitis, or lower limb sepsis, were included in the study after obtaining written informed consent. Patients with critical limb ischemia requiring immediate revascularization or amputation, non-diabetic peripheral vascular diseases, severe pedal edema, non-compressible arteries with ABI >1.3, pregnant women, and patients unwilling to participate were excluded from the study.

A consecutive sampling technique was employed for recruitment. All eligible diabetic foot patients presenting to the outpatient department or admitted to surgical wards during the study period were sequentially enrolled until the required sample size was achieved. The calculated sample size was 100 participants. Sample size estimation was based on the primary objective of evaluating the correlation between ABI and arterial Doppler findings. The calculation was derived from the study by Latifat Tunrayo et al., [10] which reported approximately 80% correlation between ABI and arterial Doppler findings.

Detailed demographic and clinical history including age, sex, duration and type of diabetes, smoking status, hypertension, dyslipidemia, and glycemic control were recorded. Clinical examination included assessment of ulcer characteristics, ulcer side and site, lower limb sepsis, peripheral neuropathy, and Wagner ulcer grading. Glycated hemoglobin (HbA1c) levels were documented.

Ankle–brachial index was measured using standard Doppler-assisted sphygmomanometric technique. Patients were examined in supine position after adequate rest. Systolic blood pressure was measured in both brachial arteries and at the dorsalis pedis and posterior tibial arteries of both lower limbs using a handheld Doppler probe. ABI was calculated by dividing the higher ankle systolic pressure by the higher brachial systolic pressure. ABI values <0.9 were considered suggestive of peripheral arterial disease.

All participants subsequently underwent lower limb arterial Doppler ultrasonography for assessment of arterial patency, waveform morphology, peak systolic velocity (PSV), end diastolic velocity (EDV), and evidence of stenosis or occlusion. Doppler waveforms were categorized as triphasic, biphasic, or monophasic according to severity of arterial compromise.

Data were entered and analyzed using appropriate statistical software. Continuous variables were expressed as mean ± standard deviation, while categorical variables were expressed as frequency and percentage. Student's t-test and Chi-square test were applied for comparison between groups. Correlation between ABI and Doppler parameters was assessed using correlation analysis. Receiver operating characteristic (ROC) curve analysis was performed to evaluate diagnostic utility of ABI for prediction of PAD. Logistic regression analysis was used to identify predictors of PAD on Doppler ultrasonography. A p-value <0.05 was considered statistically significant.

RESULTS

A total of 100 patients with diabetic foot were included in the study. The mean age of participants was 60.62 ± 12.16 years (range: 40–80 years). Most patients belonged to the 60–69 years and 70–79 years age groups (28% each). There was near equal sex distribution with 51% males and 49% females. The mean duration of diabetes was 14.34 ± 6.51 years, with Type 2 diabetes accounting for 95% of cases.

Lower limb sepsis was present in 70% of patients, while peripheral neuropathy was noted in 74%. Forefoot ulcers were the most common (60%), and Wagner grade 2 ulcers constituted the largest subgroup (42%). Smoking history was present in 63% of patients, hypertension in 53%, and dyslipidemia in 48%. Mean HbA1c was 9.99 ± 1.00%, indicating poor glycemic control in the study population.

Table 1. Baseline demographic and clinical characteristics of study participants (n = 100)

Variable	Value
Age (years), mean ± SD	60.62 ± 12.16
Male sex, n (%)	51 (51%)
Duration of diabetes (years), mean ± SD	14.34 ± 6.51
Type 2 diabetes, n (%)	95 (95%)
Lower limb sepsis, n (%)	70 (70%)
Peripheral neuropathy, n (%)	74 (74%)
Current smokers, n (%)	43 (43%)
Hypertension, n (%)	53 (53%)
Dyslipidemia, n (%)	48 (48%)
HbA1c (%), mean ± SD	9.99 ± 1.00

ABI assessment demonstrated a mean worse-limb ABI of 0.84 ± 0.28. Abnormal ABI values were observed in 54% of patients, while 6% had non-compressible vessels. Doppler examination revealed monophasic flow in 49% of limbs and moderate stenosis in 55% of cases. Peripheral arterial disease was detected in 60% of patients by ABI and in 69% by arterial Doppler ultrasonography.

Table 2. ABI and Doppler characteristics of study population

Variable	Value
Worse limb ABI, mean ± SD	0.84 ± 0.28
Right ABI, mean ± SD	0.90 ± 0.29
Left ABI, mean ± SD	0.90 ± 0.30
Abnormal ABI, n (%)	54 (54%)
Borderline ABI, n (%)	14 (14%)
Non-compressible ABI, n (%)	6 (6%)
Monophasic flow pattern, n (%)	49 (49%)
Moderate stenosis by PSV, n (%)	55 (55%)
Mean PSV (cm/s), mean ± SD	220.85 ± 66.40
Mean EDV (cm/s), mean ± SD	20.96 ± 8.75
PAD by ABI, n (%)	60 (60%)
PAD by Doppler, n (%)	69 (69%)

Patients with Doppler-confirmed PAD had significantly lower ABI values compared to patients without PAD (0.73 ± 0.25 vs 1.08 ± 0.17; t = −8.13, p < 0.0001). Female sex was significantly associated with PAD on Doppler examination (79.6% vs 58.8%; p = 0.0425). Ulcer side also demonstrated significant association with PAD status (p = 0.0062). However, age, duration of diabetes, Wagner ulcer grade, lower limb sepsis, and type of diabetes were not significantly associated with PAD.

Table 3. Association of clinical variables with Doppler-confirmed PAD

Variable	PAD Present	PAD Absent	p value
Age (years), mean ± SD	61.64 ± 11.71	58.35 ± 13.01	0.2344
Duration of diabetes (years), mean ± SD	14.78 ± 6.37	13.35 ± 6.81	0.3270
Worse limb ABI, mean ± SD	0.73 ± 0.25	1.08 ± 0.17	<0.0001*
Female sex, n (%)	39/49 (79.6%)	10/49 (20.4%)	0.0425*
Wagner grade 4–5, n (%)	14/17 (82.4%)	3/17 (17.6%)	0.4412

A highly significant association was observed between ABI category and Doppler-confirmed PAD (χ^2 = 57.094, p < 0.0001). Among patients with abnormal ABI, 94.4% had PAD on Doppler examination. Similarly, monophasic flow pattern and abnormal PSV categories demonstrated strong association with PAD status (p < 0.0001 for both).

Table 4. Correlation between ABI categories and Doppler-confirmed PAD

ABI Category	PAD Present n (%)	PAD Absent n (%)
Abnormal ABI	51 (94.4%)	3 (5.6%)
Borderline ABI	11 (78.6%)	3 (21.4%)
Non-compressible ABI	4 (66.7%)	2 (33.3%)
Normal ABI	3 (11.5%)	23 (88.5%)

Chi Square value: 57.094, p value- <0.0001

Correlation analysis demonstrated a strong negative correlation between ABI and Peak Systolic Velocity (r = −0.623, p < 0.0001), and a moderate negative correlation with End Diastolic Velocity (r = −0.544, p < 0.0001). ABI category showed significant positive correlation with Doppler parameters. Wagner ulcer grade demonstrated weak, non-significant correlation with ABI (r = −0.139, p = 0.1672).

Table 5. Correlation between ABI and Doppler parameters

Parameter	Correlation coefficient (r)	p value
Peak systolic velocity (PSV)	−0.623	<0.0001*
End diastolic velocity (EDV)	−0.544	<0.0001*
ABI category	+0.534	<0.0001*
Wagner ulcer grade	−0.139	0.1672

Receiver operating characteristic (ROC) analysis showed excellent diagnostic performance of ABI for prediction of Doppler-confirmed PAD with an AUC of 0.888. The optimal ABI cutoff value determined using Youden's index was 0.88, which yielded sensitivity of 82% and specificity of 81%. Positive predictive value was 91.7%, while overall diagnostic accuracy was 81%.

Table 6. Diagnostic performance of ABI for prediction of PAD

Parameter	Value
Optimal ABI cutoff	0.88
Sensitivity	82%
Specificity	81%
Positive predictive value	91.7%
Negative predictive value	65.0%
Overall diagnostic accuracy	81.0%
AUC	0.888

On multivariate logistic regression analysis, worse limb ABI emerged as an independent predictor of Doppler-confirmed PAD (OR = 0.0017; 95% CI: 0.0002–0.015; p = 0.0004). Wagner ulcer grade was not independently associated with PAD. The model demonstrated good fit with Nagelkerke R^2 of 0.62 and overall classification accuracy of 85%.

Table 7. Logistic regression analysis for predictors of PAD

Variable	OR	95% CI	p value
Worse limb ABI	0.0017	0.0002–0.015	0.0004*
Wagner ulcer grade	1.405	0.820–2.412	0.2148

Model Performance	Value
Model Chi-square	52.70
Nagelkerke R^2	0.62
Overall classification accuracy	85%

DISCUSSION

Peripheral arterial disease is a major determinant of morbidity in diabetic foot patients and significantly increases the risk of non-healing ulcers, gangrene, and lower limb amputation. Early identification of vascular compromise remains critical for prevention of adverse outcomes.

This cross-sectional study evaluated 100 consecutive diabetic foot patients, demonstrating strong and clinically meaningful correlation between ABI and arterial Doppler ultrasonography, and validating ABI as a practical OPD-based screening tool for PAD. The study population was representative of real-world diabetic foot clinics: predominantly older (mean age 60.62 years), with long-standing Type 2 diabetes (mean duration 14.34 years), poor glycemic control (mean HbA1c 9.99%), and multiple atherosclerotic risk factors - comparable to characteristics reported by Oduola-Owoo et al. (2022). [10]

PAD prevalence was 60% by ABI and 69% by Doppler. The higher Doppler-detected prevalence aligns with the established concept that calcified arteries yield falsely normal ABI values in diabetic patients. Oduola-Owoo et al. reported abnormal Doppler waveforms in 60.6% of posterior tibial and 58.5% of dorsalis pedis arteries, substantially exceeding their ABI abnormality rate of 22.3%. (10) Hur et al. (2018) demonstrated that 23.8% of patients with ABI 0.91–1.40 had clinically significant PAD (≥50% stenosis) on color Doppler, with older age, smoking, and leg symptoms as independent predictors. [11] Nativel et al. (2018) similarly concluded that ABI performance is highly variable in diabetic populations due to medial arterial calcification and neuropathy, and that no single alternative test currently provides superior standalone utility. [12] In the present study, 35% of ABI-negative patients still harboured Doppler-confirmed PAD, reinforcing the limitations of ABI as a sole exclusion test.

The core finding of a strong negative correlation between ABI and PSV ($r = -0.623$, $p < 0.001$) is physiologically coherent. As arterial stenosis worsens, the post-stenotic pressure gradient increases, reducing distal ankle pressures while simultaneously elevating velocity at the stenosis site. Arita et al. (2020) corroborated this principle, demonstrating significant correlations between ABI and hemodynamic indices including percentage of mean arterial pressure (%MAP; $r = -0.425$, $p < 0.001$) and upstroke time ($r = -0.304$, $p = 0.017$) in patients undergoing endovascular treatment. [13] The moderate negative correlation between ABI and EDV ($r = -0.544$, $p < 0.001$) further indicates that lower ABI is associated with altered distal resistance reflected in end-diastolic flow patterns.

Doppler waveform findings were equally compelling. Monophasic flow was present in 49% of limbs; only 23% retained normal triphasic waveforms. PAD prevalence increased progressively with waveform deterioration: 91.8% in monophasic, 67.9% in biphasic, and 21.7% in triphasic groups ($\chi^2 = 35.981$, $p < 0.001$). This physiologically expected gradient demonstrates the clinical value of qualitative Doppler waveform analysis as a PAD severity marker. Rawan Ali et al. (2022), using triplex ultrasound in 100 diabetic participants, demonstrated that HbA1c levels strongly correlated with resistive index values in foot arteries — consistent with the uniformly high HbA1c (mean 9.99%) and high Doppler PAD burden in the present cohort. [14]

ROC analysis demonstrated excellent ABI discrimination (AUC 0.888). The empirically derived optimal cutoff of 0.88 yielding 82% sensitivity and 81% specificity is slightly below the conventional 0.9 threshold. Roshan et al. (2024) reported AUC 0.804 against duplex ultrasound (sensitivity 67.9%, specificity 94.4%), demonstrating good but slightly lower overall performance - a difference likely reflecting cohort composition and PAD definition differences. [15] The high PPV of 91.7% confirms that an abnormal ABI is strongly predictive of true Doppler PAD and supports its role as a rule-in screening tool. However, the NPV of 65.0% confirms that a normal ABI cannot reliably exclude PAD in diabetic foot patients. Yang et al. (2021) demonstrated that low ABI (<1.0) was independently associated with diabetic foot ulcers (adjusted OR 2.712), supporting ABI as a meaningful vascular risk predictor. [16]

Logistic regression confirmed ABI as the strongest independent predictor of Doppler PAD (OR 0.0017 per unit ABI increase, $p < 0.001$), while Wagner ulcer grade was non-significant ($p = 0.215$). This has critical clinical implications: ulcer morphological severity should not be used as a proxy for vascular status, and structured vascular assessment must be integrated into evaluation of all diabetic foot patients regardless of ulcer depth or grade. Soyoye et al. (2021) emphasized that PAD is frequently underdiagnosed in diabetic populations because clinical attention disproportionately focuses on neuropathy, and that PAD is an equally important etiological factor in adverse limb outcomes. (17) The significant association between Doppler PAD and planned surgical management ($\chi^2 = 42.64$, $p < 0.001$) demonstrates that vascular assessment directly influences treatment intensity and limb-salvage planning.

One of the strengths were that this study employed a dual-modality, operator-blinded design with comprehensive statistical analysis including ROC, correlation, and logistic regression across a broad Wagner Grade 1–5 cohort, directly linking vascular findings to clinical management outcomes. Some limitations were that it had a single-center cross-sectional design, with absence of angiographic validation, small subgroups for Type 1 DM and higher Wagner grades, lack of toe-brachial index in calcified vessels, and unanalysed confounders including renal function and medication use.

CONCLUSION

The present study demonstrated significant correlation between ankle–brachial index and arterial Doppler findings in diabetic foot patients. Lower ABI values were associated with abnormal Doppler flow patterns and increased prevalence of peripheral arterial disease. ABI is a simple, cost-effective, and useful screening tool for early detection of PAD in diabetic foot patients, particularly in outpatient and resource-limited settings.

However, arterial Doppler ultrasonography remains essential for detailed vascular evaluation and confirmation of disease, especially in patients with suspected arterial calcification or equivocal ABI values. Combined use of ABI and Doppler assessment may improve diagnostic accuracy, facilitate early intervention, and contribute to better limb salvage outcomes in diabetic foot disease.

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