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Utility Of Hba1c, Ankle-Brachial Pressure Index and Doppler Scan to Predict Amputation in Diabetic Foot

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ABSTRACT

Introduction: *Diabetes mellitus (DM) is a chronic metabolic disorder associated with microvascular and macrovascular complications, among which diabetic foot ulcers (DFUs) are particularly disabling. Peripheral arterial disease (PAD) contributes significantly to the development of chronic wounds, infections, and amputations in diabetic patients. Glycated hemoglobin (HbA1c) remains a reliable marker for long-term glycaemic control and may also reflect vascular compromise. This study aimed to evaluate the relationship between HbA1c levels, ankle-brachial pressure index (ABPI), and Doppler findings with the severity of vasculopathy in patients with DFUs, while also assessing the prognostic role of HbA1c in wound healing and risk of amputation.*

Materials and Methods: *A cross-sectional observational study was conducted at Adichunchanagiri Institute of Medical Sciences, Adichunchanagiri University, B.G. Nagara, Mandya, over 18 months. A total of 87 patients with diabetic foot ulcers were enrolled. Clinical evaluation included peripheral pulse assessment, ABPI measurement, and arterial Doppler examination. HbA1c levels were stratified as <7.5% and >7.5%. Statistical analysis was performed using SPSS version 26.0.*

Results: *The cohort had a mean age of 60.48 ± 12.65 years, with male predominance (80.5%). Poor glycaemic control (HbA1c >9%) was observed in 58.6% of patients. ABPI indicated claudication in 60.9% and severe arterial disease in 2.3%. Higher HbA1c levels were significantly associated with greater PAD severity ($p < 0.05$), delayed wound healing, and higher amputation risk.*

Conclusion: *Elevated HbA1c correlates strongly with worsening PAD and poor wound healing in diabetic foot patients. Early vascular assessment and strict glycaemic control are essential to improve outcomes and reduce amputations.*

Keywords: *Diabetic foot ulcer; Glycated hemoglobin; Peripheral arterial disease*

INTRODUCTION

Diabetes mellitus (DM) is a chronic metabolic disorder of global significance, affecting individuals across diverse socioeconomic backgrounds. The prevalence of DM continues to rise, with nearly half a billion people currently diagnosed worldwide, and projections indicate an increase of more than 50% in the next 25 years. The disease is associated with multiple complications, primarily involving vascular damage, which manifests as both microvascular and macrovascular sequelae, including retinopathy, nephropathy, neuropathy, and atherosclerotic disease affecting the brain, heart, and lower limbs [1]. Among these, lower extremity complications are particularly debilitating, affecting an estimated 131 million people globally,

with a prevalence of approximately 1.8% [2]. These complications significantly contribute to morbidity and mortality, often resulting in chronic ulcers, recurrent infections, and amputations.
Diabetic foot ulcers (DFUs) represent a major clinical concern, profoundly impacting patients' quality of life and increasing healthcare burdens. The global incidence of DFUs is approximately 2% per year, with lifetime prevalence reaching up to 15% among individuals with diabetes. These ulcers are associated with poor prognosis, often progressing to non-healing wounds, infections, and amputations, which account for up to 70% of all lower limb amputations in diabetic patients [3]. The primary factors contributing to DFU formation include peripheral neuropathy, peripheral arterial disease (PAD), foot deformities, and repetitive trauma [4,5]. While neuropathy leads to sensory loss and unrecognized injuries, PAD results from atherosclerotic narrowing of lower limb arteries, causing chronic ischemia, delayed wound healing, increased infection susceptibility, and a heightened risk of amputation [6]. Despite its critical role, PAD is often underemphasized compared to neuropathy, with many patients remaining asymptomatic until advanced stages, highlighting the need for early detection and intervention.
Glycaemic control is a crucial determinant of vascular health in diabetic patients. Hemoglobin A1c (HbA1c), formed through non-enzymatic glycation of hemoglobin, is a gold-standard biomarker reflecting average blood glucose over the preceding two to three months [9–13]. Elevated HbA1c levels are strongly associated with both microvascular and macrovascular complications, including PAD. Chronic hyperglycemia induces endothelial dysfunction, oxidative stress, and pro-inflammatory states that accelerate atherosclerosis and impair wound healing [14]. Studies have demonstrated that higher HbA1c levels correlate with increased severity of PAD, worsening ischemia, and elevated risk of adverse limb outcomes, including amputations. Consequently, HbA1c may serve as an important indicator of vascular complications in diabetic foot patients [15].
Given the rising global burden of diabetes and its associated complications, early identification of high-risk patients is critical to prevent progression to severe outcomes. Diabetic foot ulceration often results from a combination of neuropathy and PAD, making the assessment of vascular status essential for patient management. The present study aims to evaluate the relationship between HbA1c levels, the severity of PAD as assessed by ankle-brachial pressure index (ABPI) and Doppler studies, and the risk of amputation.

MATERIALS AND METHODS

This prospective cross-sectional study was conducted over a period of 18 months at the Department of General Surgery, Adichunchanagiri Institute of Medical Sciences, Adichunchanagiri University, B.G. Nagara, Nagamangala Taluk, Mandya District. The study population included adult patients aged above 18 years presenting with diabetic foot. Patients willing to participate and providing written informed consent were included, while those who were pregnant, had malignancy, end-organ failure, or other macrovascular/microvascular complications were excluded. Purposive sampling was employed to recruit participants. The minimum required sample size was calculated using the formula n=z2pq/d2n = z^2pq/d^2, with a prevalence (p) of 25%, allowable error (d) of 25%, and a confidence constant (z) of 1.96, yielding a minimum sample size of 82 participants. A total of 87 patients were enrolled in the study. Demographic and clinical data were collected using a structured pre-designed questionnaire through face-to-face interviews. The Wagner–Meggitt classification system was applied to grade diabetic foot ulcers, and comorbidities were recorded according to the American Society of Anesthesiologists (ASA) criteria. Decisions regarding amputation or re-amputation were made by a multidisciplinary diabetic foot committee based on clinical findings, including gangrenous skin changes, necrosis, foul odor indicating anaerobic infection, and progression despite medical management. Diagnostic support included assessment of irreversible ischemic changes using the ankle-brachial pressure index (ABPI) and vascular Doppler ultrasound.
The ABPI procedure was performed using a handheld Doppler device and sphygmomanometer with patients in the supine position. Systolic pressures were recorded in both brachial arteries and in the anterior tibial, posterior tibial, and dorsalis pedis arteries of each limb. The ABPI was calculated as the ratio of the highest ankle systolic pressure to the highest brachial systolic pressure. ABPI values >1.0 were considered normal; 0.5–0.9 indicated claudication; and <0.5 indicated severe arterial disease with potential for ischemic ulceration, rest pain, or gangrene.
Laboratory investigations included hemoglobin (Hb), white blood cell count (WBC), albumin, glycated hemoglobin (HbA1c), C-reactive protein (CRP), and serum creatinine. Radiological assessments,

including vascular Doppler, were performed to support diagnosis and management. Postoperative care involved glycaemic control, daily wound dressing, monitoring of blood parameters, rehabilitation, and prosthesis application if required. Complete wound healing without recurrence over six months was considered a successful outcome.

Data were entered in MS Excel and analyzed using SPSS version 26.0. Quantitative variables are presented as mean ± standard deviation (SD), and qualitative variables as frequency and percentage. Comparison of continuous variables was performed using Student's t-test, and categorical variables were compared using the χ^2 test. A p-value <0.05 was considered statistically significant.

RESULTS

The study population comprised 87 participants with a mean age of 60.48 ± 12.65 years. Most individuals were in the 61–70 years age group (36.8%), followed by 51–60 years (27.6%), and the smallest proportion was in the 30–40 years group (8.0%). There was a marked male predominance, with 80.5% males and 19.5% females, reflecting a predominantly middle-aged to elderly male population (Table 1).

Table 1. Demographic Characteristics of Study Participants (N = 87)

Variable	Category	Frequency	Percentage
Age (years)	30–40	7	8.0%
	41–50	11	12.6%
	51–60	24	27.6%
	61–70	32	36.8%
	>70	13	14.9%
	Total	87	100.0%
Sex	Male	70	80.5%
	Female	17	19.5%
	Total	87	100.0%

Glycaemic control among participants was poor, with 58.6% having HbA1c levels >9, 29.9% between 6.5–9, and only 11.5% below 6.5, indicating well-managed diabetes in a minority. Peripheral arterial disease was prevalent, as evidenced by an ABPI <0.9 in 63.2% of participants (claudication 60.9%, severe arterial disease 2.3%), while 36.8% had normal ABPI values. Amputations were infrequent, occurring in 5.7% of participants, whereas the majority (94.3%) did not undergo amputation (Table 2).

Table 2. Clinical Characteristics of Study Participants (N = 87)

Variable	Category	Frequency	Percentage	Mean ± SD
HbA1c	<6.5	10	11.5%	9.81 ± 2.53
	6.5 – 9	26	29.9%	
	>9	51	58.6%	
ABPI	Normal	32	36.8%	0.88 ± 0.23
	Claudication	53	60.9%	
	Severe arterial disease	2	2.3%	
Amputation	Yes	5	5.7%	-
	No	82	94.3%	

Clinical examination of arterial pulsations demonstrated that all participants had palpable femoral pulses (100%), while popliteal pulsations were present in 95.4% (right) and 96.6% (left). Pulses of the anterior tibial artery were palpable in 55.2% bilaterally, posterior tibial in 63.2%, and dorsalis pedis in 49.4% (right) and 44.8% (left), indicating a gradient of distal arterial compromise (Table 3).

Table 3. Distribution of Arterial Pulsations on Clinical Examination (N = 87)

Arterial Pulsation	Right	Left
Femoral	87 (100.0%)	87 (100.0%)
Popliteal	83 (95.4%)	84 (96.6%)
Anterior tibial (ATA)	48 (55.2%)	48 (55.2%)
Posterior tibial (PTA)	55 (63.2%)	55 (63.2%)
Dorsalis pedis (DPA)	43 (49.4%)	39 (44.8%)

Ultrasound assessment of lower limb arteries revealed that a substantial proportion of participants did not undergo evaluation (right: 40–46%, left: 40–43%). Among those assessed, higher-grade vascular abnormalities (Grade 3) were most frequent in all arterial sites, with femoral artery Grade 3 observed in 46% (right) and 54% (left), popliteal in 46% and 40.2%, and similar trends in anterior tibial, dorsalis pedis, and posterior tibial arteries, highlighting significant peripheral arterial disease (Table 4).

Table 4. Ultrasound (USG) Findings of Lower Limb Arteries (N = 87)

Site	Grade	Right	Left
Femoral	**Not done**	35 (40.2%)	35 (40.2%)
	Grade 1	2 (2.3%)	2 (2.3%)
	Grade 2	9 (10.3%)	2 (2.3%)
	Grade 3	40 (46.0%)	47 (54.0%)
Popliteal	**Not done**	36 (41.3%)	36 (41.3%)
	Grade 1	5 (5.7%)	4 (4.6%)
	Grade 2	41 (47.1%)	11 (12.6%)
	Grade 3	40 (46.0%)	35 (40.2%)
Anterior tibial (ATA)	**Not done**	36 (41.3%)	37 (42.5%)
	Grade 1	16 (18.4%)	22 (25.3%)
	Grade 2	12 (13.8%)	12 (13.8%)
	Grade 3	19 (21.8%)	15 (17.2%)
Dorsalis pedis (DPA)	**Not done**	40 (45.9%)	38 (43.6%)
	Grade 1	17 (19.5%)	21 (24.1%)
	Grade 2	11 (12.6%)	12 (13.8%)
	Grade 3	18 (20.7%)	15 (17.2%)
Posterior tibial (PTA)	**Not done**	37 (42.5%)	38 (43.6%)
	Grade 1	18 (20.7%)	15 (17.2%)
	Grade 2	10 (11.5%)	13 (14.9%)
	Grade 3	21 (24.1%)	20 (23.0%)

Wound severity, based on the Wagner classification, showed that nearly half of the participants had Grade 2 wounds (48.3%), followed by Grade 3 (26.4%), Grade 4 (14.9%), and Grade 1 (10.3%), reflecting a population with predominantly moderate to severe diabetic foot ulcers (Table 5).

Table 5. Wagner Wound Grading of Participants (N = 87)

Wagner Grade	Frequency	Percentage
Grade 1	9	10.3%
Grade 2	42	48.3%
Grade 3	23	26.4%
Grade 4	13	14.9%
Total	**87**	**100.0%**

Analysis of ABPI in relation to Wagner wound grades, HbA1c, and amputation status demonstrated that higher wound grades and poorer glycaemic control were associated with lower ABPI values. Mean ABPI decreased progressively from Grade 1 (0.91 ± 0.25) to Grade 3 (0.80 ± 0.20) and Grade 4 (0.81 ± 0.22) wounds ($p = 0.042$). Similarly, participants with HbA1c >9 had lower ABPI (0.81 ± 0.22) compared to those with HbA1c <6.5 (0.94 ± 0.26) ($p = 0.050$). Patients who underwent amputation had significantly lower ABPI (0.61 ± 0.16) compared to those without amputation (0.90 ± 0.22) ($p = 0.007$) (Table 6).

Table 6: ABPI in Relation to Wagner Wound Grading and HbA1c

Variable	Category	Mean ABPI ± SD	p-value
ABPI vs Wagner grade	**Grade 1**	0.91 ± 0.25	**0.042**
	Grade 2	0.95 ± 0.24	
	Grade 3	0.80 ± 0.20	
	Grade 4	0.81 ± 0.22	
ABPI vs HbA1c	**<6.5**	0.94 ± 0.26	**0.050**

	6.5 – 9	0.89 ± 0.24	
	>9	0.81 ± 0.22	
ABPI vs Amputation	**Yes**	0.61 ± 0.16	**0.007**
	No	0.90 ± 0.22	

Correlation analysis revealed a strong negative correlation between HbA1c and ABPI (r = -0.772, p <0.001) and a weaker but significant inverse correlation between Wagner wound grade and ABPI (r = -0.241, p = 0.025), indicating that poorer glycaemic control and higher wound severity are associated with worsening peripheral arterial disease (Table 7).

Table 7: Correlation of ABPI with HbA1c and Wagner Wound Grading

Variable	Pearson Correlation (r)	p-value
HbA1c vs ABPI	-0.772	<0.001
Wagner wound grade vs ABPI	-0.241	0.025

DISCUSSION

Diabetic foot complications remain a major contributor to morbidity, disability, and healthcare burden among patients with diabetes mellitus (DM). Peripheral neuropathy and peripheral arterial disease (PAD) are the primary factors driving ulcer formation, delayed wound healing, and subsequent amputations [15,16]. In the present study, the mean age of participants was 60.48 years, with the majority (36.8%) aged between 61–70 years, and a predominance of male participants (80.5%). Poor glycaemic control was prevalent, as evidenced by a mean HbA1c of 9.81 ± 2.53, with 58.6% of participants exceeding 9%. These findings align with previous reports by Hegde et al. [16] and Kumar B et al. [17], demonstrating that older male populations with prolonged diabetes duration are at increased risk for diabetic foot complications. The higher mean age in our cohort compared to Sachar et al. [18] suggests that advancing age may exacerbate vascular and neuropathic complications, influencing ulcer severity and the risk of amputation. Assessment of vascular status using the ankle-brachial pressure index (ABPI) revealed that 60.9% of participants exhibited claudication, 36.8% had normal ABPI, and 2.3% demonstrated severe arterial disease, with a mean ABPI of 0.88 ± 0.23. Evaluation of arterial pulsations indicated diminished distal circulation, with dorsalis pedis artery pulsations detected in only 49.4% on the right and 44.8% on the left limb. These observations are consistent with findings by Kumar et al. [17] and Sachar et al. [18] and highlighting the high prevalence of PAD in diabetic populations and its strong correlation with impaired distal perfusion. Ultrasound assessments further revealed that severe vascular impairment (Grade 3) was most frequent in femoral and popliteal arteries, emphasizing the extent of arterial compromise in these patients.

Wagner wound grading demonstrated that 48.3% of participants had Grade 2 ulcers, 26.4% had Grade 3, and 14.9% had Grade 4 wounds, indicating that the majority presented with moderate-to-severe ulceration. ABPI correlated inversely with Wagner grade, with higher wound grades associated with lower ABPI values (Grade 3: 0.80 ± 0.20; Grade 4: 0.81 ± 0.22; p = 0.042), suggesting that arterial insufficiency plays a pivotal role in ulcer progression. These findings are supported by Hegde et al. [16], Ghanbari et al. [19], and Akyüz et al. [20], all of whom reported statistically significant associations between poor glycaemic control, ulcer severity, and compromised vascular status. Furthermore, elevated HbA1c (>9%) correlated with lower ABPI (0.81 ± 0.22, p = 0.05), reinforcing the link between chronic hyperglycemia and PAD, in line with observations by Solanki et al. [21] and Komut et al. [22].

The study also identified a strong inverse correlation between HbA1c and ABPI (r = -0.772, p < 0.001), indicating that poor glycaemic control accelerates arterial compromise and increases the risk of ischemia, ulceration, and amputation. These findings underscore the critical importance of strict glycaemic management in mitigating vascular complications and promoting ulcer healing, consistent with prior studies highlighting the therapeutic benefits of HbA1c reduction [16-18]. Overall, the results emphasize that comprehensive assessment of both glycaemic control and vascular status is essential in guiding clinical management, preventing progression of diabetic foot ulcers, and reducing the need for lower limb amputations.

CONCLUSION

The present study demonstrates a clear relationship between poor glycaemic control, peripheral arterial disease, and the severity of diabetic foot wounds. The high prevalence of uncontrolled diabetes and claudication highlights the critical need for stringent glycaemic management and routine vascular assessment. The observed inverse correlation between ABPI and HbA1c underscores the importance of maintaining optimal glucose levels to prevent the progression of arterial insufficiency. Regular screening using ABPI and vascular ultrasound, coupled with a multidisciplinary management approach, can facilitate early detection, timely intervention, and ultimately reduce the risk of severe complications, including lower limb amputation.

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