Intrarenal Hemodynamic Alterations and Their Biochemical Correlates in Type 2 Diabetes: A Doppler Ultrasound Study

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Abstract

Background: Diabetic nephropathy (DN) is a major cause of chronic kidney disease (CKD) and end-stage renal disease worldwide. While biochemical markers such as blood urea nitrogen, serum creatinine, estimated glomerular filtration rate (eGFR), and albuminuria are routinely used, early and subclinical renal dysfunction may be missed. Renal Doppler ultrasound, particularly the resistive index (RI) and pulsatility index (PI), provides a noninvasive tool for assessing intrarenal hemodynamics. This study aimed to explore the association between common biochemical markers and renal Doppler ultrasound parameters in diabetic patients and to evaluate how factors such as glycemic control and disease duration influence these measures.
Methods and Results: A cross-sectional study was conducted on type 2 diabetes (T2D). Biochemical markers and Doppler indices were measured. Appropriate statistical tests were performed to examine relationships between biochemical and Doppler ultrasound findings. Of the 150 patients (mean age of 51.2 ± 8.4 years), 41.3% had poor glycemic control (HbA1c > 8%). Both RI and PI exhibited significant negative correlations with eGFR ($P<0.001$) and significant positive correlations with blood urea and serum creatinine. RI and PI values were noticeably higher in patients with poorer glycemic control and longer duration of diabetes. Peak systolic velocity (PSV) and end-diastolic velocity (EDV) had no significant correlation with biochemical markers ($P>0.05$).
Conclusion: In patients with T2D, there is a strong correlation between biochemical markers of renal dysfunction and renal Doppler ultrasound parameters, particularly RI and PI. These parameters worsen with poor glycemic control and longer disease duration. (**International Journal of Biomedicine. 2026;16(1):71-77.**)

Keywords: diabetes • Doppler ultrasound • resistive index • pulsatility index • eGFR

Key Points

• High intrarenal Doppler indices (RI, PI) correlate with worse eGFR stages and higher albuminuria in T2D patients.
• Poor glycemic control and longer duration of diabetes both predict more pronounced renal dysfunction on Doppler.
• Renal Doppler ultrasound holds promise as an adjunct tool for early detection and ongoing assessment of diabetic nephropathy.

Abbreviations

BMI, body mass index; **BUN**, blood urea nitrogen; **CKD**, chronic kidney disease; **DN**, diabetic nephropathy; **eGFR**, estimated glomerular filtration rate; **EDV**, end-diastolic velocity; **LK**, left kidney; **PSV**, peak systolic velocity; **PI**, pulsatility index; **RI**, resistive index; **RK**, right kidney; **T2D**, type 2 diabetes.

Introduction

Diabetes mellitus is becoming more common worldwide, which makes it a major health concern. Globally, there are currently 537 million people with diabetes mellitus. By 2045, that number is predicted to rise to 783 million.[1] Advanced age, obesity, unhealthy lifestyle choices like inactivity, and poor diet quality are all blamed for the rising incidence of disease. Countries with lower and middle incomes have a higher burden of disease.[2] In 2017, the estimated prevalence of diabetes mellitus in Africa was 3.3%, with Sudan being one of the nations with a prevalence of over 12%.[3] The most frequent causes of end-stage renal disease are diabetes. About 30% of people with diabetes develop diabetic nephropathy, one of the most common microvascular complications of the disease. One of the first indicators that diabetic nephropathy will develop is microalbuminuria.[4]

Renal ultrasonography and Doppler studies are non-invasive and are frequently used to measure kidney size, assess renal parenchymal echogenicity and vascular alterations, and rule out potential obstructive uropathy.[5] Renal Doppler imaging provides informative data on renal and intrarenal arterial flow. The renal resistive index (RI) and pulsatility index (PI), measured via non-invasive Doppler ultrasound, are considered valuable indicators for early detection of diabetic nephropathy (DN). These indices explore the blood flow resistance in the renal arteries.[6] Sugiura et al.[7] reported that an increase in renal RI has been linked with vascular lesions, tubulointerstitial damage, and glomerulosclerosis. The PI is another Doppler parameter that has not been extensively studied; most previous studies focused on RI alone. Studies conducted in Sudan have assessed Doppler imaging's utility for diagnosing diabetic nephropathy in patients with type 2 diabetes (T2D), but have not examined its correlation with other clinical and biochemical parameters. This study aimed to investigate the relationships between Doppler indices (RI, PI, PSV, and EDV) and clinical and biochemical parameters in patients with T2D, including body mass index (BMI), diabetes duration, albuminuria, HbA1C, and GFR. The outcomes of this study would aid early diagnosis and treatment of diabetic nephropathy and provide more thorough insight into its pathophysiology.

Materials and Methods

Study Design and Study Population

This hospital-based, cross-sectional study was conducted among adult diabetic patients from April 2021 to March 2023. The sample included adults aged 18 years or older with a known diagnosis of T2D and who attend diabetes or nephrology clinics in the study area. Any patient with congenital kidney abnormalities or other primary renal pathologies unrelated to diabetes and those with acute renal injury or ongoing use of nephrotoxic drugs that could confound renal function measurements were excluded. A convenience sample of 150 consecutive diabetic patients who met the inclusion criteria was enrolled.

Clinical and Demographic Data

The demographic and clinical data include age, sex, body mass index (BMI), Duration of diabetes mellitus, and Glycemic control as measured by hemoglobin A1c (HbA1c).

Biochemical Investigations

Blood Urea Nitrogen (BUN) and Serum Creatinine (Cr): Measured using automated methods in the hospital laboratory.

Estimated Glomerular Filtration Rate (eGFR): Calculated using the CKD-EPI equation.

Albuminuria: Classified as normoalbuminuria (<30 mg/day), microalbuminuria (30–300 mg/day), or macroalbuminuria (>300 mg/day).

Ultrasound Examinations

Grayscale and renal Doppler ultrasound were applied. For conventional B-mode ultrasound, the kidney dimensions (length, width, and parenchymal thickness) and cortico-medullary differentiation were assessed using a 3.5 MHz convex probe. Subsequently, intrarenal vessels (interlobar or arcuate arteries) were sampled to measure Doppler indices. The peak systolic velocity (PSV), end-diastolic velocity (EDV), and acceleration time (AT) were recorded (Figure 1). Normal RI was defined as ≤0.70; High RI was defined as >0.70, and normal PI was considered ≤1.1; High PI was defined as >1.1.

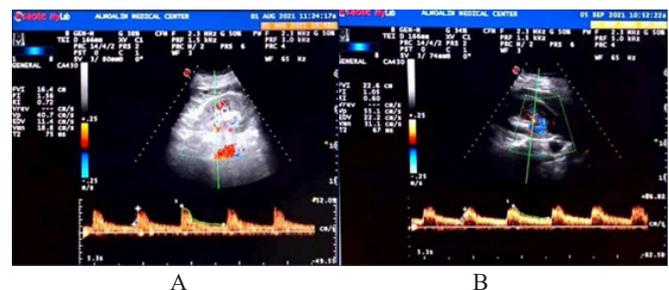**Fig. 1.** *Doppler ultrasound showing high (A) and normal (B) Resistive Index (RI) and Pulsatility Index (PI)*

Statistical Analysis

The data were analyzed using SPSS version 27 and the DATAtab online statistical calculator. In descriptive statistics, mean ± standard deviation (SD) and standard error of the mean (SEM) were used for continuous variables, and frequencies and percentages were used for categorical variables. Then the patients were stratified by eGFR stages (1–3), albuminuria categories (normo-, micro-, macroalbuminuria), glycemic control (HbA1c <7%, 7–8%, >8%), and diabetes duration (<5 years, 5–10 years, >10 years). Comparisons of means and Pearson's correlation were used to assess differences in gray-scale ultrasound parameters and Doppler indices across groups. Multiple comparisons were performed with one-way ANOVA and a post-hoc Tukey HSD test. The probability value of *P*<0.05 was considered statistically significant.

Results

A total of 150 adult T2D patients, with a mean age of 51.2 ± 8.4 years, were included in the study. Females slightly predominated (55.3%). Regarding diabetes duration, 62.7% were in the first 10 years, 25.3% in 11-20 years, and 12.3% in more than 20 years. (Table 1).

Table 1.

Baseline characteristics of the study patients.

Characters		Frequency	Percent
Age, years	30-40	23	15.3
	41-50	43	28.7
	51-60	84	56.0
Gender	Female	83	55.3
	Male	67	44.7
BMI	Underweight	19	12.7
	Normal	104	69.3
	Overweight	5	3.3
	Obese	22	14.7
T2D duration, years	0-10	94	62.7
	11-20	38	25.3
	More than 20	18	12.0
Total		150	100.0

Blood urea nitrogen (BUN) averaged 27.7±10.0 mg/dL. Serum creatinine averaged 0.90±0.33 mg/dL. Urine albumin levels averaged 25.5 ± 53.0 mg/dL, corresponding to normoalbuminuric in 82.0%, microalbuminuria in 14.7%, and macroalbuminuria in 3.3%. Based on eGFR, 64.0% of subjects were in Stage 1, 22.7% in Stage 2, and 13.3% in Stage 3 CKD. 41.3% of patients show poor glycemic control, and 55.3% show elevated BUN. (Table 2, Table 3).

Table 2.

Laboratory tests and biomarkers of the study patients.

Lab test and biomarkers	Categories	N	%
eGFR, mL/min/1.73 m²	Normal (More than 90)	96	64.0
	Stage two (60-89)	34	22.7
	Stage 3 (less than 60)	20	13.3
Albuminuria, mg/day	Normal (<30)	123	82.0
	Microalbuminuria (30-300)	22	14.7
	Macroalbuminuria (>300)	5	3.3
HbA1C, %	4-6 (excellent control)	19	12.7
	7-8 (Good control)	69	46
	> 8 (Poor)	62	41.3
Urea, mg/dL	Low	1	0.7
	Normal	66	44.0
	Elevated	83	55.3
Total		150	100.0

Table 3.

Descriptive statistics of Doppler indices in the study patients.

Parameters	Mean± SD
Age, years	51.25±8.43
BMI, kg/cm²	23.15±4.57
Duration of DM, years	11.02±7.52
Urea, mg/dL	27.72±10.23
Creatinine (cr), mg/dL	0.90±.33
eGFR, mL/min/1.73 m²	101.34±30.86
HbA1C, %	8.17±1.88
RK length, cm	10.02±.76
RK volume, cm³	147.72±43.21
R PSV, cm/sec	43.59±15.60
R EDV, cm/sec	13.72±6.64
R RI	0.70±.065
R PI	1.42±.33
R AT, msec	59.25±23.56
LK length, cm	10.11±.79
LK volume, cm³	158.02±44.45
L PSV, cm/sec	42.76±18.07
L EDV, cm/sec	13.40±5.38
L RI	0.69±.07
L PI	1.37±.30

R -right, L-left.

On Doppler assessment, the mean right RI was 0.69±0.06, and the left side was 0.68±0.06. The PI measures averaged 1.41±0.32 (right) and 1.36 ± 0.30 (left) (Table 3).

The RI and PI revealed significant positive correlations with biomarkers of renal function, such as urea and creatinine (for RI: r=0.498 and r=0.5 [RK] and r=0.488 and r=0.495 [LK], respectively ($P<0.0001$ in all cases), while for PI: r=0.508 and r=0.553 [RK] and r=0.481 and r=0.501 [LK], respectively, $P<0.001$ in all cases)). A significant negative correlation between the indices (RI, PI) and eGFR was observed in both kidneys ($P<0.001$). Furthermore, the age of T2D patients shows a weak positive correlation with Doppler PI and RI (Table 4, Figures 2 and 3). There was no significant correlation between PSV, AT, and the duration of T2D, urea, Cr, GFR, and HbA1C (Table 4).

Regarding the relationship between kidney gray-scale measurements in T2D with normal and decreased eGFR, it was found that as eGFR decreased, kidney size and volume decreased slightly. At the same time, PSV and AT slightly increased with each reduction in eGFR. These variations were insignificant. The parameters most affected by reduced kidney function were PI and RI, which were significantly higher in patients with eGFR<90 mL/min/1.73 m² than in those with eGFR ≥90 mL/min/1.73 m² ($P<0.001$) (Table 5).

The study found a weak positive linear association between RI and Cr ($R^2=0.25$ for both kidneys) (Figure 5), as well as between RI and urea ($R^2=0.24$ for RK and $R^2=0.23$ for LK) (Figure 6). There was an inverse weak linear association between GFR and RI in both kidneys ($R^2=0.25$ for LK and $R^2=0.24$ for RK) (Figure 7).
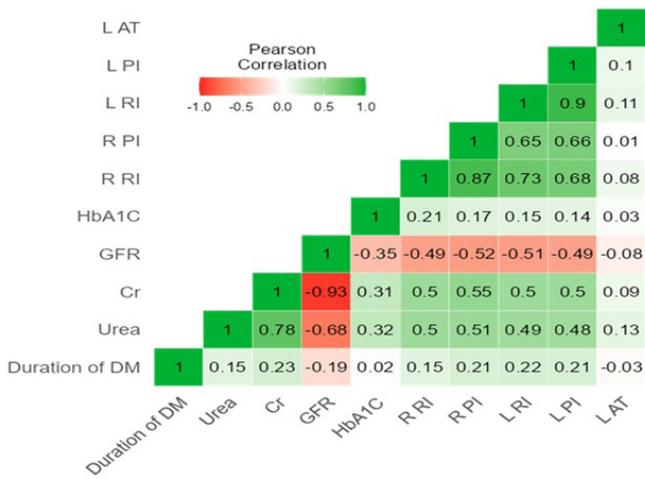
Fig.2. *Correlation heatmap to assess the relationship between duration, lap profile, and Doppler parameters in the T2D group.*
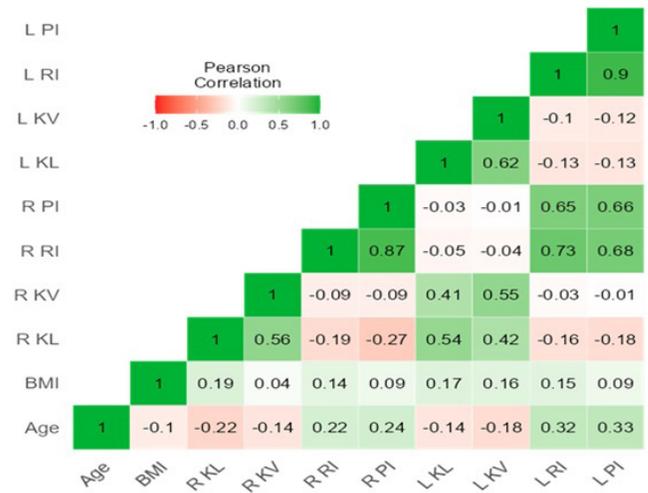

Fig.3. *Correlation heatmap to assess the relationship between gray-scale ultrasound and Doppler parameters in the T2D group.*

Table 4.

Results of the correlation analysis.

		Duration of T2D	Urea	Cr	GFR	HbA1C
R PSV	Pearson Correlation	-0.012	0.084	0.013	-0.010	0.093
	Sig. (2-tailed)	0.880	0.308	0.879	0.908	0.256
L PSV	Pearson Correlation	-0.132	-0.008	-0.068	0.035	0.000
	Sig. (2-tailed)	0.106	0.923	0.409	0.671	0.999
R RI	Pearson Correlation	0.150	**0.498**	**0.500**	**-0.489**	**0.205**
	Sig. (2-tailed)	0.067	<0.001	<0.001	<0.001	0.012
R PI	Pearson Correlation	**0.209**	**0.508**	**0.553**	**-0.524**	**0.174**
	Sig. (2-tailed)	0.010	<0.001	<0.001	<0.001	0.033
R AT	Pearson Correlation	-0.040	0.030	-0.009	0.023	0.010
	Sig. (2-tailed)	0.624	0.719	0.908	0.779	0.904
L RI	Pearson Correlation	**0.216**	**0.488**	**0.495**	**-0.507**	0.146
	Sig. (2-tailed)	0.008	<0.001	<0.001	<0.001	0.074
L PI	Pearson Correlation	**0.215**	**0.481**	**0.501**	**-0.490**	0.143
	Sig. (2-tailed)	0.008	<0.001	<0.001	<0.001	0.081
L AT	Pearson Correlation	-0.026	0.131	0.086	-0.078	0.029
	Sig. (2-tailed)	0.750	0.109	0.297	0.342	0.722

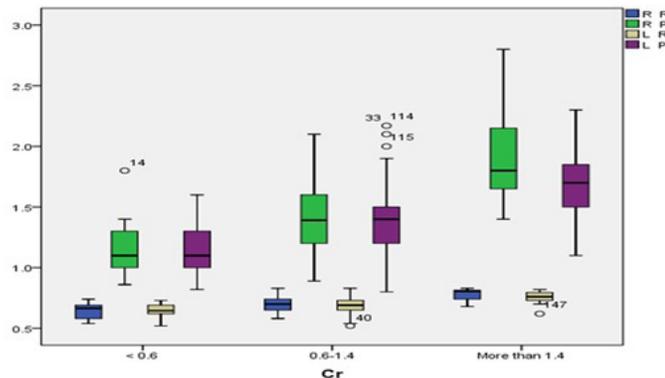*R – right, L – left, Weak Pearson correlation, Moderate Pearson correlation*

Fig. 4. *Plot box for comparing mean kidney measurements and Doppler indices among T2D patients with normal, low, and elevated Cr levels.*

Table 5.
Kidney measurements and Doppler indices in T2D patients with normal and low eGFR (mL/min/1.73 m²).

Parameters	eGFR	N	Mean	SD	SEM	*P*-value
RK length, cm	≥90	96	10.031	0.7624	0.0778	0.744
	<90	54	9.989	0.7615	0.1036	
RK volume, cm³	≥90	96	146.876	46.0301	4.6979	0.740
	<90	54	149.206	38.0462	5.1774	
R PSV, cm/sec	≥90	96	43.304	14.9719	1.5281	0.771
	<90	54	44.106	16.7952	2.2855	
R RI	≥90	96	0.6822	0.06315	0.00645	<.001
	<90	54	0.7289	0.05881	0.00800	
R PI	≥90	96	1.3203	0.26431	0.02698	<.001
	<90	54	1.5898	0.35347	0.04810	
R AT, msec	≥90	96	58.90	23.468	2.395	0.810
	<90	54	59.87	23.928	3.256	
LK length, cm	≥90	96	10.169	0.8278	0.0845	0.199
	<90	54	10.002	0.7178	0.0977	
LK volume, cm³	≥90	96	159.668	48.4076	4.9406	0.515
	<90	54	155.083	36.6076	4.9817	
L PSV, cm/sec	≥90	96	42.526	17.8538	1.8222	0.835
	<90	54	43.178	18.6090	2.5324	
L RI	≥90	96	0.6675	0.06209	0.00634	<0.001
	<90	54	0.7196	0.05798	0.00789	
L PI	≥90	96	1.2871	0.27132	0.02769	<0.001
	<90	54	1.5148	0.29908	0.04070	
L AT, msec	≥90	96	57.48	21.500	2.194	0.229
	<90	54	62.57	29.816	4.057	
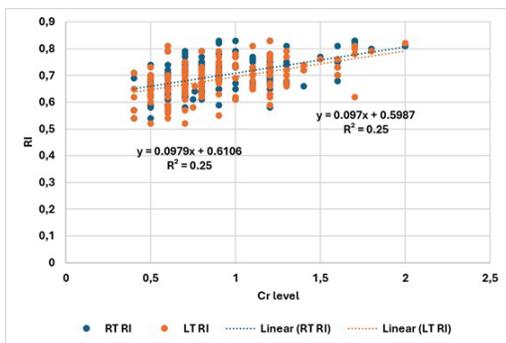
Fig. 5. Relationship between RI and Cr level.

Fig. 6. Relationship between RI and urea level.

Fig. 7. Relationship between RI and eGFR.

The study found that as albuminuria increased, Doppler RI and PI increased significantly (*P*<0.001 (Table 6).

Discussion

Numerous renal diseases, including obstructive kidney disease,[8] renovascular hypertension,[9] and parenchymal renal disease,[10] have been examined using Doppler imaging sonography. We noninvasively examined intrarenal hemodynamic changes in patients with T2D using sonography and Doppler imaging. It was found that T2D patients with nephropathy, characterized by elevated albuminuria and renal insufficiency, exhibited intrarenal hemodynamic alterations. Kidney diseases have been evaluated using the intrarenal RI and PI, measures of renal vascular alterations. Most previous studies used only RRI to evaluate renal artery flowmetry. The significance of this study is that it uses all Doppler parameters (RI, PI, PSV, EDV, and AT), which are associated with a faster decline in renal function.
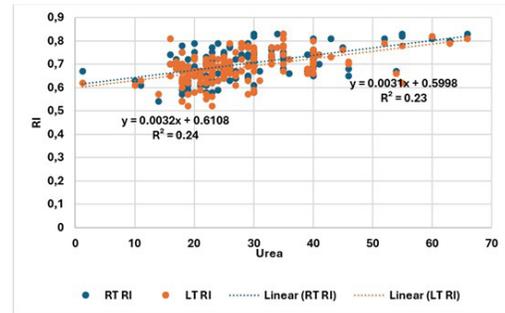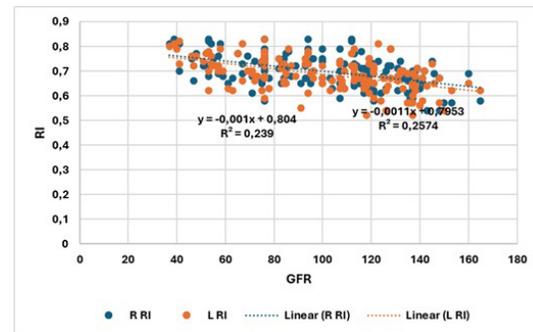
Table 6.
Kidney measurements and Doppler indices among T2D patients with different albuminuria ranges.

Albuminuria		R RI	*P*-value	R PI	*P*-value	L RI		L PI	*P*-value
<30 mg/day n=123 [1]	Mean	0.68	F=43.8495 P=0.0000 P_{1-2}=0.0000 P_{1-3}=0.0000 P_{2-3}=0.4259	1.34	F=25.2487 P=0.0000 P_{1-2}=0.0000 P_{1-3}=0.0001 P_{2-3}=0.4483	0.67	F=40.2075 P=0.0000 P_{1-2}=0.0000 P_{1-3}=0.0000 P_{2-3}=0.9081	1.30	F=30.9016 P=0.0000 P_{1-2}=0.0000 P_{1-3}=0.0000 P_{2-3}=0.0991
	SD	0.05		0.29		0.05		0.25	
30-300 mg/day n=22 [2]	Mean	0.77		1.73		0.76		1.66	
	SD	0.04		0.25		0.04		0.25	
> 300 mg/day n=5 [3]	Mean	0.80		1.9		0.77		1.92	
	SD	0.04		0.32		0.03		0.35	
Total	Mean	0.70		1.42		0.67		1.37	
	SD	0.07		0.32		0.06		0.30	

The study found that the RI and PI of the renal arteries in diabetic patients correlated significantly with biomarkers of renal function, such as urea and creatinine. It was also observed that both RI and PI were negatively correlated with GFR. In agreement with this finding, a previous study reported that serum creatinine and HbA1c were statistically significantly positively correlated with both RI and PI.[11] Additionally, Khalifa reported that the RI had a significant positive correlation with albuminuria, urea, creatinine, and HbA1c.[5] Ishimura et al.[12] reported that RRI values were significantly affected by creatinine clearance and duration of DM. The changes in PI and RI indicate severe renal hemodynamic dysfunction. These changes are caused by advanced microvascular damage, decreased renal compliance, and increased vascular stiffness.[13]

The present study found a strong negative relationship between Doppler parameters (RI and PI) and eGFR in both kidneys. Consistently, Guarav et al. reported a significant inverse relationship between RRI and eGFR.[14] Soyoye et al.[15] also reported a negative relationship between eGFR and PI and RI. Both PI and RI were significantly elevated when eGFR<90 mL/min/1.73 m². This elevation in RI reflects intrarenal vascular resistance, indicating increased renal vascular resistance and microvascular alterations linked to diabetic nephropathy. This correlation may be used as an early objective indicator of renal impairment. Therefore, both PI and RI are helpful, non-invasive methods for tracking disease course and assessing risk in diabetic patients.

The other Doppler parameters, PSV and EDV, showed no significant association with eGFR in our study. In agreement with this finding, Chen et al. reported that eGFR was not significantly correlated with PSV or EDV.[16] They reported that the PSV increased significantly with CKD progression.

Some studies found moderate-to-strong correlations between PSV, EDV, and eGFR, whereas others reported no significant association.[17,18] This could be attributed to variations in patient populations, study methodologies, and the specific arteries measured (renal artery vs. intrarenal arteries). While renal artery PSV and EDV may be influenced by factors such as age and may not directly correlate with eGFR as intrarenal Doppler parameters do, some studies suggest that interlobar EDV is a powerful indicator of renal function.

Uncontrolled diabetes affects kidney vascularity and can be detected by elevated RI and PI. In this study, the RI and PI increased significantly with HbA1C, showing a positive linear correlation. In agreement with this finding, Sharma et al. reported that RI and PI exhibited a statistically significant positive connection with HbA1c.[11] Additionally, Miyoshi et al. reported a positive correlation of RI with HbA1c.[19] In contrast, Lotfinejad and Khan reported that RI was not significantly correlated with HbA1c.[20,21]

The study found significant positive correlations between T2D duration and PI, as well as between T2D duration and RI. Nasir et al.[22] also found a significant correlation between renal RI and T2D duration. Additionally, Youseff and Fawzy [23] reported that the increase in RI correlated significantly with the duration of DM. Most of these studies focused on the impact of renal RI rather than PI. However, our study found that PI has

the same impact, and when used together, they could provide accurate results and a better evaluation of renal vascularity in diabetic patients.

The study found that the renal artery RI and PI increased significantly in patients with macroalbuminuria compared to those with microalbuminuria and no albuminuria, as reported by Hamano et al.[24] Consistent with our findings, they also found that the RI values were higher in DM patients with albuminuria than in those without albuminuria. Nosadini et al.[25] reported that increased renal RI can predict progression of renal function in T2D with microalbuminuria, even when GFR remains normal.

In general, this study supports the use of renal Doppler ultrasonography as a useful supplement to biochemical evaluation in DN. The consistent associations between RI and PI and indicators such as creatinine, urea, HbA1c, albuminuria, and eGFR highlight that kidney vascular alterations can be identified before any obvious biochemical decline. Together with data from earlier studies, these results suggest that incorporating Doppler parameters into clinical practice may improve the early detection of renal impairment, especially in patients with long disease duration or poor glycemic control. Renal Doppler assessment, when used in conjunction with standard laboratory testing, offers a more thorough understanding of the course of diabetic kidney disease and may help direct prompt interventions to reduce its burden.

This study has some limitations that should be considered. Firstly, the relationship between the biochemical markers and the Doppler indices might be affected by temporal changes and disease progression. In addition, the study was conducted at a single tertiary care center and used a convenience sample of 150 patients, which further limits the generalizability of the results. In addition, the potential confounding factors of co-existing hypertension, use of nephrotoxic drugs, and other microvascular changes may not be adequately controlled. Also, the inter- and intra-observer variability of Doppler measurements could affect the reproducibility of some results. Further longitudinal multi-center studies with larger, more representative, and more diverse populations are needed to generalize the study findings.

Conclusion

Our study highlights the significant correlations between biochemical markers of renal function (especially eGFR and albuminuria) and Doppler ultrasound findings (RI and PI) in diabetic patients. Poor glycemic control and longer disease duration are each linked to higher Doppler indices and worse biochemical profiles, underscoring the multifactorial nature of DN progression. These results support the adjunctive value of renal Doppler in early detection and monitoring of DN, encouraging clinicians to combine biochemical and Doppler imaging assessments to optimize patient outcomes.

Ethical Considerations

This study received ethical approval for publication from the Ethics Committee at College of Graduate Studies, Karary

University (Khartoum, Sudan). All participants received a clear explanation of the study's purpose and objectives and provided verbal approval to participate.

Availability of Data and Materials

The data of this study are available from the corresponding author upon a justifiable request.

Conflicts of Interest

The authors declare no conflict of interest in this study.

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