

Renal Resistive Index and Cardiometabolic Risk Factors in Patients with Chronic Kidney Disease

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Abstract

Background

The renal resistive index (RRI) is a Doppler-derived parameter that may reflect both intrarenal hemodynamics and systemic vascular characteristics. Its relationship with renal disease severity and cardiometabolic factors in patients with chronic kidney disease (CKD) remains incompletely defined. This study aimed to identify clinical, renal, and cardiometabolic factors independently associated with RRI in patients with CKD.

Methods

This cross-sectional study included 100 adults with CKD. Bilateral renal Doppler ultrasonography was performed, and mean bilateral RRI was calculated as the arithmetic mean of the right and left RRI measurements. Clinical and laboratory data included age, body mass index, blood pressure, HbA1c, lipid profile, serum albumin, estimated glomerular filtration rate (eGFR), urinary albumin-to-creatinine ratio (UACR), and previous cardiovascular disease. Spearman's rank correlation was used to assess associations between RRI and continuous variables. RRI according to previous cardiovascular disease was compared using the Mann–Whitney U test, while differences across CKD stages were assessed using the Kruskal–Wallis test with Bonferroni-adjusted pairwise comparisons. Multivariable linear regression was performed to identify independent factors associated with mean bilateral RRI.

Results

The mean age was 51.5 ± 10.9 years, and 52% of participants were male. The mean bilateral RRI was 0.699 ± 0.058 . Mean RRI showed a strong inverse correlation with eGFR (Spearman's $p = -0.771$, $P < 0.001$) and a strong positive correlation with serum creatinine ($p = 0.772$, $P < 0.001$). Moderate positive correlation was observed with UACR ($p = 0.391$, $P < 0.001$), while HbA1c showed a weak positive correlation ($p = 0.291$, $P = 0.003$) and serum albumin showed a moderate inverse correlation ($p = -0.560$, $P < 0.001$). RRI differed significantly across CKD stages (Kruskal–Wallis $H = 58.733$, $P < 0.001$). In multivariable analysis, the model explained 70.3% of the variance in mean RRI (adjusted $R^2 = 0.661$, $P < 0.001$). Higher HbA1c ($B = 0.006647$, $P = 0.008$) and LDL-C ($B = 0.000391$, $P = 0.003$) were independently associated with higher RRI, whereas higher eGFR ($B = -0.001378$, $P < 0.001$) and serum albumin ($B = -0.023033$, $P = 0.021$) were independently associated with lower RRI. Previous cardiovascular disease was not significantly associated with RRI ($P = 0.558$).

Conclusion

Mean bilateral RRI was strongly associated with renal functional impairment and differed significantly across CKD stages. HbA1c and LDL-C were independently associated with higher RRI, while serum albumin was independently associated with lower RRI. These findings suggest that RRI may reflect both renal disease severity and systemic cardiometabolic characteristics in patients with CKD. Prospective studies are warranted to determine the prognostic significance of these associations.

Keywords: Renal resistive index; chronic kidney disease; cardiometabolic risk factors; estimated glomerular filtration rate; albuminuria; renal Doppler ultrasonography.

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Introduction

Chronic kidney disease (CKD) is a major global health problem and is strongly associated with an increased burden of cardiovascular morbidity and mortality.

Cardiovascular risk in CKD reflects the interaction between conventional risk factors, including diabetes mellitus, hypertension, obesity, and dyslipidemia, and

kidney-specific abnormalities such as reduced glomerular filtration and increased albuminuria. The 2024 kidney disease: Improving Global Outcomes (KDIGO) Clinical Practice Guideline emphasizes the assessment of both estimated glomerular filtration rate (eGFR) and albuminuria for CKD classification and risk assessment and recommends that cardiovascular risk assessment in CKD incorporate eGFR and albuminuria where appropriate [1].

The coexistence of cardiometabolic abnormalities and CKD is clinically important because diabetes, abnormal blood pressure, and dyslipidemia contribute to vascular injury while declining kidney function may further amplify cardiovascular risk. Contemporary evidence emphasizes that cardiovascular disease is a major contributor to the excess morbidity and mortality associated with CKD, with diabetes, blood pressure abnormalities, and lipid disturbances representing important, shared risk factors [2]. Consequently, identification of vascular markers that reflect the interaction between renal and systemic vascular abnormalities may provide additional insight into cardiovascular risk in patients with CKD.

The renal resistive index (RRI) is a Doppler ultrasonographic parameter derived from intrarenal arterial waveforms and calculated as the difference between peak systolic velocity and end-diastolic velocity divided by peak systolic velocity. Although it was initially interpreted primarily as an index of intrarenal vascular resistance, subsequent physiological and clinical evidence has demonstrated that RRI is influenced by both renal and systemic hemodynamic properties. Arterial compliance, pulse pressure, vascular stiffness, age, and other systemic factors may substantially affect the Doppler waveform from which RRI is derived [3,4]. Thus, RRI may reflect the interaction between renal microcirculation and the systemic vascular system rather than isolated renal vascular resistance.

The potential cardiovascular relevance of RRI has been demonstrated in several clinical populations. In hypertensive patients, higher RRI values have been associated with measures of cardiovascular target-organ damage, including left ventricular hypertrophy, carotid atherosclerosis, and microalbuminuria [5]. More recent observational evidence has also reported an association between RRI and estimated cardiovascular risk after adjustment for traditional risk factors in individuals with hypertension [6]. These findings support continued investigation of RRI as a marker of systemic vascular alterations, while

recognizing that its interpretation is influenced by renal function and other hemodynamic determinants.

Despite increasing evidence linking RRI with systemic vascular characteristics, the relationship between RRI and individual cardiometabolic risk factors in patients with CKD remains incompletely characterized. It is important to distinguish associations with cardiometabolic factors from those attributable to the severity of underlying kidney disease, as eGFR and albuminuria are themselves strongly related to cardiovascular and renal outcomes in CKD [1]. Therefore, the present study aimed to investigate the association between RRI and selected cardiometabolic risk factors, including blood pressure, body mass index, glycemic control, lipid parameters, and previous cardiovascular or cerebrovascular disease, among patients with CKD, while considering eGFR and urinary albumin-to-creatinine ratio (UACR) as important renal covariates.

Objectives

The present study aimed to evaluate the relationship between renal resistive index (RRI) and cardiometabolic risk factors in patients with chronic kidney disease (CKD).

The specific objectives were to:

- 1-Determine the RRI in patients with CKD using renal Doppler ultrasonography.
- 2- Assess the association of RRI with cardiometabolic factors, including glycemic control, blood pressure, BMI, lipid profile, and previous cardiovascular disease.
- 3-Evaluate the relationship between RRI and CKD severity, particularly eGFR and UACR.
- 4-Determine the independent predictors of RRI after considering relevant cardiometabolic factors and renal disease severity.

Patients and Methods

Study design and participants

This cross-sectional study included 100 adults with chronic kidney disease (CKD) attending the Nephrology and Diabetes outpatient clinics at Minia University Hospitals, Egypt, between May 2024 and June 2026. Participants were evaluated clinically, biochemically, and by renal Doppler ultrasonography.

Ethical approval

The study protocol was reviewed and approved by the Institutional Research Ethics Committee of the Faculty of Medicine, Minia University, Egypt, before participant enrollment (approval number: **906/09/2023**; approval date: **20 September 2023**). Written informed consent was obtained from all participants before enrollment.

Clinical and cardiometabolic assessment

Demographic and clinical data were collected, including age, sex, previous cardiovascular disease (CVD), blood pressure, and body mass index (BMI). Cardiometabolic variables included glycemic control, assessed by glycated hemoglobin (HbA1c), and lipid parameters, including total cholesterol, triglycerides, LDL-C, and VLDL-C.

Laboratory assessment

Blood samples were obtained for measurement of serum creatinine, estimated glomerular filtration rate (eGFR), HbA1c, total cholesterol, triglycerides, LDL-C, VLDL-C, serum albumin. Urinary albumin-to-creatinine ratio (UACR) was measured using a first-morning spot urine sample. CKD stage was classified according to eGFR.

Renal resistive index assessment

Renal Doppler ultrasonography was performed by a consultant radiologist who was blinded to the clinical and laboratory data. The renal resistive index (RRI) was calculated from Doppler measurements of the interlobar or arcuate renal arteries using the following equation:

$$\text{RRI} = (\text{PSV} - \text{EDV}) / \text{PSV}$$

where PSV represents peak systolic velocity and EDV represents end-diastolic velocity. RRI was recorded separately for the right and left kidneys, and the mean bilateral RRI was calculated as the arithmetic mean of the right and left RRI measurements and used as the primary outcome.

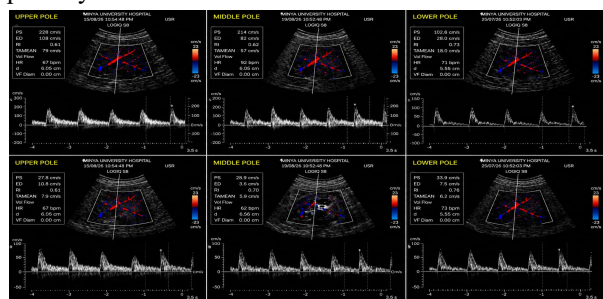


Figure X. Representative renal Doppler ultrasonographic assessment of the renal resistive index in a patient with chronic kidney disease and cardiometabolic risk factors. A 55-year-old male patient with a history of hypertension for >5 years, body mass index of 26.5 kg/m², urinary albumin-to-creatinine ratio of 150 mg/g, and serum creatinine of 1.0 mg/dL. Color and spectral Doppler measurements were obtained from the upper, middle, and lower poles of both kidneys (A–F). The mean renal resistive index across the six measurements was 0.67. RRI was calculated as (peak systolic velocity – end-diastolic

velocity)/peak systolic velocity. PSV, peak systolic velocity; EDV, end-diastolic velocity; RRI, renal resistive index

Source: Original data from the present study

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables were summarized as mean $\pm$ standard deviation (SD) or median (interquartile range [IQR]), as appropriate, and categorical variables as frequencies and percentages. The Shapiro–Wilk test was used to assess normality. Spearman’s rank correlation coefficient (ρ) was used to assess associations between mean bilateral RRI and clinical, cardiometabolic, and renal variables. The Mann–Whitney U test was used to compare RRI according to previous cardiovascular disease, and the Kruskal–Wallis test with Bonferroni-adjusted pairwise comparisons was used to compare RRI across CKD stages. Multivariable linear regression using the Enter method was performed to identify independent factors associated with mean bilateral RRI. Multicollinearity was assessed using variance inflation factor (VIF) values. A two-sided P value <0.05 was considered statistically significant.

Results

Table 1. Clinical, biochemical, renal, and renal resistive index characteristics of the study population (n = 100)

Variable	Study population
Age, years	51.54 $\pm$ 10.88
Male sex, n (%)	52 (52.0)
Female sex, n (%)	48 (48.0)
Previous cardiovascular disease, n (%)	18 (18.0)
BMI, kg/m ²	26.75 $\pm$ 2.10
SBP, mmHg	121.33 $\pm$ 8.57
DBP, mmHg	73.47 $\pm$ 8.39
HbA1c, %	5.50 (2.53)
Total cholesterol, mg/dL	206.50 $\pm$ 38.68
Triglycerides, mg/dL	140 (40)
LDL-C, mg/dL	85.50 (40)
VLDL-C, mg/dL	40 (20)
Serum albumin, g/dL	3.50 (1.00)
Serum creatinine, mg/dL	2.20 (2.25)
eGFR, mL/min/1.73 m ²	35 (49)
UACR, mg/g	750 (1797.5)
CKD stage	
Stage 1, n (%)	10 (10.0)
Stage 2, n (%)	19 (19.0)

Stage 3, n (%)	26 (26.0)
Stage 4, n (%)	34 (34.0)
Stage 5, n (%)	11 (11.0)
Right RRI	0.686 ± 0.061
Left RRI	0.711 ± 0.056
Mean bilateral RRI	0.699 ± 0.058

Continuous variables are presented as mean ± standard deviation (SD) or median (interquartile range [IQR]), according to data distribution. Categorical variables are presented as number (percentage). RRI, renal resistive index; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; HbA1c, glycated hemoglobin; LDL-C, low-density lipoprotein cholesterol; VLDL-C, very-low-density lipoprotein cholesterol; eGFR, estimated glomerular filtration rate; UACR, urinary albumin-to-creatinine ratio.

The study included 100 patients with CKD (table 1), with a mean age of 51.5 years and a relatively balanced sex distribution. Previous cardiovascular disease was reported in 18% of participants. Renal impairment was substantial, with a median eGFR of 35 mL/min/1.73 m² and the largest proportions of patients classified as CKD stages 3 and 4. Albuminuria was prominent, with a median UACR of 750 mg/g. The mean bilateral RRI was 0.699 ± 0.058, with mean right and left RRI values of 0.686 ± 0.061 and 0.711 ± 0.056, respectively.

Table 2. Spearman correlations between mean bilateral renal resistive index and clinical, cardiometabolic, and renal parameters in patients with chronic kidney disease

Parameter	Spearman's P value rho	
Age, years	0.128	0.203
BMI, kg/m ²	−0.136	0.177
SBP, mmHg	0.069	0.492
DBP, mmHg	0.031	0.761
HbA1c, %	0.291	0.003**
Total cholesterol, mg/dL	0.041	0.685
Triglycerides, mg/dL	−0.009	0.931
LDL-C, mg/dL	0.144	0.152
VLDL-C, mg/dL	0.123	0.223
eGFR, mL/min/1.73 m ²	−0.771	<0.001**
UACR, mg/g	0.391	<0.001**
Serum creatinine, mg/dL	0.772	<0.001**
Serum albumin, g/dL	−0.560	<0.001**

Spearman's rho was used because the relevant variables did not meet normality assumptions. RRI, renal resistive index; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; HbA1c, glycated hemoglobin; LDL-C, low-density

lipoprotein cholesterol; VLDL-C, very-low-density lipoprotein cholesterol; eGFR, estimated glomerular filtration rate; UACR, urine albumin-to-creatinine ratio. **P < 0.01.

Mean bilateral RRI showed a strong inverse correlation with eGFR (Spearman's ρ = −0.771, P < 0.001) and a strong positive correlation with serum creatinine (ρ = 0.772, P < 0.001). UACR was moderately positively correlated with mean bilateral RRI (ρ = 0.391, P < 0.001). HbA1c showed a weak positive correlation with RRI (ρ = 0.291, P = 0.003), whereas serum albumin showed a moderate inverse correlation (ρ = −0.560, P < 0.001). No statistically significant correlations were observed for age, BMI, systolic or diastolic blood pressure, total cholesterol, triglycerides, LDL-C, or VLDL-C.

Mean bilateral RRI did not differ significantly according to previous cardiovascular disease (Mann–Whitney U = 673.5, Z = −0.586, P = 0.558). The mean rank was 54.08 among participants with previous cardiovascular disease and 49.71 among those without previous cardiovascular disease.

Mean bilateral RRI differed significantly across CKD stages (Kruskal–Wallis H = 58.733, df = 4, P < 0.001). In Bonferroni-adjusted pairwise comparisons, significant differences were observed between stages 1 and 3 (adjusted P = 0.027), stages 1 and 4 (adjusted P < 0.001), stages 1 and 5 (adjusted P < 0.001), stages 2 and 4 (adjusted P < 0.001), stages 2 and 5 (adjusted P < 0.001), stages 3 and 4 (adjusted P = 0.003), and stages 3 and 5 (adjusted P = 0.028). No significant differences were observed between stages 1 and 2, stages 2 and 3, or stages 4 and 5.

Table 3. Multivariable linear regression analysis of factors associated with mean bilateral renal resistive index

Variable	B	SE	β	t	P value
Age, years	0.000	0.000	−0.031	−0.455	0.650
BMI, kg/m ²	0.000	0.002	−0.010	−0.158	0.875
SBP, mmHg	8.966 × 10 ^{−5}	0.001	0.013	0.164	0.870
DBP, mmHg	5.880 × 10 ^{−5}	0.001	0.009	0.102	0.919
HbA1c, %	0.006647	0.002	0.186	2.737	0.008
Total cholesterol, mg/dL	0.000	0.000	−0.090	−1.203	0.232
Triglycerides, mg/dL	−2.089 × 10 ^{−5}	0.000	−0.022	−0.323	0.747
LDL-C, mg/dL	0.000391	0.000	0.231	3.089	0.003
Previous CVD	−0.006	0.010	−0.039	−0.589	0.557

eGFR, mL/min/1.73 m ²	-0.0013780.000	-0.705	-9.634	<0.001
UACR, mg/g 10 ⁻⁶	-2.276 ×	0.000	-0.053	-0.6430.522
Serum albumin, g/dL	-0.0230330.010	-0.215	-2.357	0.021

Model summary: R=0.838; R²=0.703; adjusted R²=0.661; standard error of the estimate=0.03376; F=16.740; P<0.001; n=98.

Footnote: Dependent variable: mean bilateral RRI (RRI_MEAN). Predictors were entered simultaneously using the Enter method. B, unstandardized regression coefficient; SE, standard error; β , standardized regression coefficient; CVD, cardiovascular disease; eGFR, estimated glomerular filtration rate; UACR, urine albumin-to-creatinine ratio. P<0.05 was considered statistically significant.

The multivariable linear regression model explained 70.3% of the variance in mean bilateral RRI (R²=0.703; adjusted R²=0.661; P<0.001). Higher HbA1c (B=0.006647, P=0.008) and higher LDL-C (B=0.000391, P=0.003) were independently associated with higher mean bilateral RRI, whereas higher eGFR (B=-0.001378, P<0.001) and higher serum albumin (B=-0.023033, P=0.021) were independently associated with lower RRI. Triglycerides were not independently associated with RRI (B=-2.089×10⁻⁵, P=0.747). No statistically significant independent associations were observed for age, BMI, systolic blood pressure, diastolic blood pressure, total cholesterol, previous cardiovascular disease, or UACR.

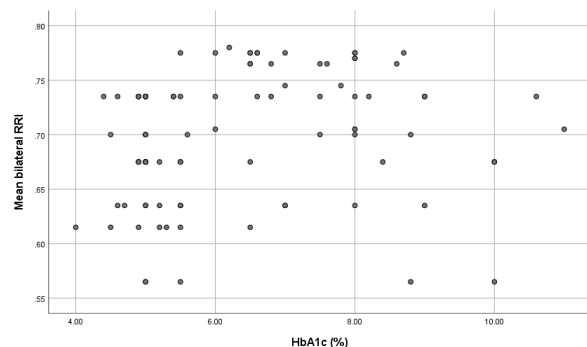


Figure 1. Scatter plot shows the association between mean bilateral renal resistive index and HbA1c in patients with chronic kidney disease. Spearman's $\rho = 0.291$, P = 0.003.

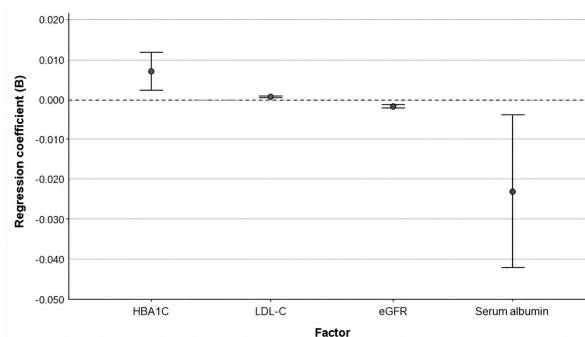


Figure 2. Multivariable associations between selected clinical, cardiometabolic, and renal factors and mean bilateral renal resistive index. Points represent unstandardized regression coefficients (B), and vertical bars represent 95% confidence intervals. The horizontal dashed line represents the null value (B = 0).

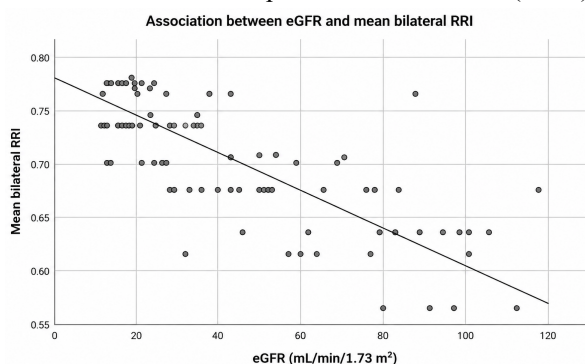


Figure 3. Scatter plot showing the inverse association between estimated glomerular filtration rate (eGFR) and mean bilateral renal resistive index in patients with chronic kidney disease. Spearman's $\rho = -0.771$, P < 0.001.

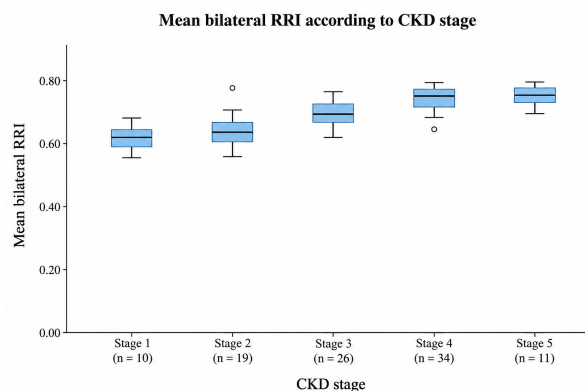


Figure 4. Box-and-whisker plot showing the distribution of mean bilateral renal resistive index according to CKD stage. Mean bilateral RRI differed significantly across CKD stages (Kruskal-Wallis H=58.733, df=4, P<0.001). Pairwise comparisons were adjusted using the Bonferroni correction.

DISCUSSION

The present study evaluated the relationship between mean bilateral renal resistive index (RRI) and renal and cardiometabolic characteristics in patients with chronic kidney disease (CKD). The principal findings were that mean bilateral RRI was strongly inversely correlated with estimated glomerular filtration rate (eGFR) and strongly positively correlated with serum creatinine. RRI also showed a moderate positive correlation with urinary albumin-to-creatinine ratio (UACR), a weak positive correlation with HbA1c, and a moderate inverse correlation with serum albumin. In the multivariable analysis, higher HbA1c and LDL-C were independently associated with higher RRI, whereas higher eGFR and serum albumin were independently associated with lower RRI. In addition, RRI differed significantly across CKD stages. In contrast, age, BMI, blood pressure, total cholesterol, triglycerides, previous cardiovascular disease, and UACR were not independently associated with RRI after adjustment for the other variables.

RRI and renal function

The strong inverse association between RRI and eGFR observed in the present study is consistent with previous evidence linking higher RRI with impaired renal function and more advanced CKD. In our cohort, eGFR showed a strong inverse correlation with mean bilateral RRI (Spearman's $\rho = -0.771$, $P < 0.001$), and eGFR remained the strongest independent correlate of RRI in the multivariable model ($\beta = -0.705$, $P < 0.001$). Furthermore, RRI distributions differed significantly across CKD stages. Previous studies have similarly demonstrated that RRI increases with worsening CKD stage and is associated with reduced eGFR. Hanamura et al. reported progressive increases in RRI across CKD stages, with significant relationships between RRI, eGFR, and renal histological damage [9]. Similarly, Sugiura and Wada demonstrated that elevated RRI was associated with subsequent deterioration of renal function during follow-up in patients with CKD [7,8].

These findings support the concept that RRI reflects the severity of renal disease, although RRI should not be considered a substitute for conventional measures of kidney function. Current KDIGO recommendations continue to classify and risk-stratify CKD primarily according to eGFR and albuminuria [1]. The physiological interpretation of RRI is also more complex than a direct measurement of renal vascular resistance. Evidence suggests that RRI is influenced by intrarenal hemodynamics as well as systemic vascular

properties, arterial stiffness, pulse pressure, and vascular compliance [3,4,12].

RRI, albuminuria, and renal disease severity

Mean bilateral RRI was moderately positively correlated with UACR in the present study ($\rho = 0.391$, $P < 0.001$). This finding is consistent with previous studies demonstrating relationships between increased RRI and albuminuria or proteinuria. In a study of patients with CKD, Sugiura and Wada reported that proteinuria and high RRI were independent predictors of worsening renal function [8]. Other studies in hypertensive populations have also demonstrated associations between elevated RRI and albuminuria [5,10].

However, UACR was not independently associated with RRI in our multivariable model ($P = 0.522$). This difference between the univariable and multivariable analyses suggests that the relationship between RRI and albuminuria may partly overlap with other measures of renal dysfunction, particularly eGFR. It is therefore more appropriate to interpret RRI and albuminuria as complementary rather than interchangeable indicators of renal disease. Importantly, the present cross-sectional design does not permit determination of whether increased RRI precedes or follows worsening albuminuria.

RRI and HbA1c

An important finding was the independent association between HbA1c and mean bilateral RRI. HbA1c showed a weak positive correlation with RRI in the univariable analysis ($\rho = 0.291$, $P = 0.003$) and remained independently associated with RRI after adjustment for renal function and other cardiometabolic variables ($B = 0.006647$, $P = 0.008$). This suggests that glycemic status may contribute to variation in renal vascular Doppler characteristics among patients with CKD.

The finding should nevertheless be interpreted cautiously. RRI is influenced by multiple systemic and renal factors, and the cross-sectional design of the present study does not establish a causal relationship between glycemic status and RRI. Previous literature has demonstrated that RRI may be associated with systemic vascular abnormalities in patients with hypertension and diabetes, even when renal function is relatively preserved [4,5,12]. Thus, the association observed in our study may reflect the combined effects of metabolic and vascular alterations rather than a direct effect of HbA1c on renal vascular resistance.

RRI and LDL-C

LDL-C was not significantly correlated with RRI in the univariable analysis ($\rho = 0.144$, $P = 0.152$), but it became

independently associated with RRI in the multivariable model ($B=0.000391$, $P=0.003$). This difference suggests that the relationship between LDL-C and RRI may be influenced by other clinical characteristics and becomes apparent after adjustment for renal function and the other cardiometabolic variables included in the model.

Previous studies have emphasized the relationship between RRI and systemic vascular abnormalities rather than renal vascular resistance alone. Tedesco et al. demonstrated associations between RRI and carotid intima-media thickness, left ventricular mass, and other manifestations of cardiovascular target-organ damage in hypertensive patients [5]. Similarly, studies investigating arterial stiffness have demonstrated relationships between RRI, pulse-wave velocity, pulse pressure, and atherosclerotic burden [11]. These observations provide a potential physiological context for the independent association between LDL-C and RRI observed in our study, although our data cannot establish a causal pathway.

RRI and serum albumin

Serum albumin demonstrated a moderate inverse correlation with mean bilateral RRI ($\rho=-0.560$, $P<0.001$) and remained independently associated with RRI in the multivariable analysis ($B=-0.023033$, $P=0.021$). Thus, lower serum albumin was associated with higher RRI after adjustment for renal and cardiometabolic variables.

This finding should be interpreted cautiously because serum albumin is a nonspecific clinical marker and can be influenced by several factors, including nutritional status and systemic disease. The present study does not provide sufficient information to determine the mechanism underlying this association. Nevertheless, the persistence of the association after adjustment suggests that variability in RRI may involve systemic characteristics in addition to renal filtration. This interpretation is consistent with evidence that RRI represents the interaction between renal microcirculation and systemic vascular hemodynamics [3,4,12].

RRI and cardiovascular disease

Previous cardiovascular disease was not significantly associated with mean bilateral RRI in the present study. Participants with previous cardiovascular disease had a mean rank of 54.08 compared with 49.71 among those without previous cardiovascular disease, with no statistically significant difference (Mann-Whitney $U=673.5$, $Z=-0.586$, $P=0.558$).

This finding differs from several previous studies linking increased RRI with cardiovascular target-organ damage and cardiovascular risk. Tedesco et al. reported associations between higher RRI and left ventricular hypertrophy, carotid atherosclerosis, increased carotid intima-media thickness, and microalbuminuria in hypertensive patients [5]. In a large CKD cohort, Toledo et al. found that an $RRI \geq 0.70$ was associated with higher mortality after adjustment for renal and cardiovascular risk factors [6]. More recent literature has continued to investigate RRI as a marker reflecting systemic vascular characteristics and cardiovascular risk [12].

The absence of a significant association with previous cardiovascular disease in our study should therefore not be interpreted as evidence that RRI is unrelated to cardiovascular abnormalities. Differences in sample size, underlying cardiovascular phenotype, CKD severity, definition of previous cardiovascular disease, and methods used to assess cardiovascular damage may explain the differences between studies. In addition, our study included only 100 participants, with 18 participants having previous cardiovascular disease, which limits the statistical power of this comparison.

Overall interpretation

Taken together, the findings suggest that RRI in patients with CKD reflects a combination of renal functional impairment and systemic/metabolic characteristics. The particularly strong association between RRI and eGFR, together with the significant differences across CKD stages, emphasizes the relationship between RRI and renal disease severity. At the same time, the independent associations with HbA1c, LDL-C, and serum albumin indicate that renal filtration alone does not explain all of the variability in RRI.

This interpretation is consistent with the evolving understanding of RRI as a parameter influenced by both renal and systemic hemodynamics. Current reviews emphasize the contribution of arterial stiffness, pulse pressure, vascular compliance, and systemic cardiovascular characteristics to RRI values [3,4,12]. Therefore, RRI may provide complementary information about the renal-vascular interface, but it should be interpreted alongside established measures of renal function, albuminuria, and cardiovascular risk rather than as an isolated measure of renal vascular resistance.

Conclusion

In this study of patients with chronic kidney disease, mean bilateral renal resistive index (RRI) was strongly

associated with renal functional impairment, showing a strong inverse relationship with eGFR and significant differences across CKD stages. RRI was also positively correlated with serum creatinine and UACR. Among cardiometabolic factors, HbA1c and LDL-C were independently associated with higher RRI, whereas higher serum albumin was independently associated with lower RRI. Previous cardiovascular disease was not significantly associated with RRI in this cohort.

These findings suggest that RRI reflects a combination of **renal functional impairment and systemic cardiometabolic characteristics** rather than renal vascular resistance alone. RRI may therefore provide complementary information when evaluating patients with CKD, particularly when interpreted alongside eGFR, albuminuria, and conventional cardiometabolic risk factors. However, the cross-sectional design precludes causal inference, and larger prospective studies are needed to determine the prognostic value of RRI and its potential role in monitoring CKD progression and cardiovascular risk.

Strengths and limitations

The present study has several strengths. Bilateral renal Doppler measurements were obtained and summarized as mean bilateral RRI, reducing dependence on a measurement from a single kidney. The analysis also included a broad range of renal and cardiometabolic variables. In addition, renal disease was evaluated using both continuous measures of renal function and categorical CKD stages, while multivariable regression was used to identify independent associations with RRI.

Several limitations should be acknowledged. First, the cross-sectional design prevents determination of temporal or causal relationships between RRI and the studied variables. Second, the sample size was relatively small and derived from a single center, which may limit generalizability. Third, some CKD stages contained relatively few participants, which may reduce the precision of stage-specific comparisons. Fourth, potentially important determinants of RRI, including arterial stiffness, pulse pressure, cardiac function, and detailed medication exposure, were not comprehensively assessed. Finally, residual confounding cannot be excluded despite multivariable adjustment.

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