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Renal Resistive Index and Doppler-Derived Intrarenal Hemodynamic Parameters as Non-Invasive Prognostic Markers Across Stages of Chronic Kidney Disease: A Hospital-Based Observational Study.

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Abstract

Background: Chronic kidney disease (CKD) imposes a substantial and rising global burden, and reliable non-invasive prognostic markers are needed to refine risk stratification. Doppler-derived intrarenal hemodynamic indices — renal resistive index (RRI), peak systolic velocity (PSV) and end-diastolic velocity (EDV) — are increasingly recognised as candidate prognostic markers, but their stage-wise behaviour and relative predictive strength remain underutilised in routine practice. ***Objectives:*** To evaluate the association of RRI, PSV and EDV with KDIGO CKD stage and to assess their correlation with estimated glomerular filtration rate (eGFR). ***Methods:*** A hospital-based observational study was conducted in the Department of General Medicine, Mahatma Gandhi Medical College & Hospital, Jaipur, between April 2024 and September 2025. One hundred consecutive adults (18–65 years) with CKD were enrolled. Patients with kidney transplants, renal artery stenosis, acute kidney injury, immunocompromised states or pregnancy were excluded. All participants underwent renal duplex Doppler ultrasonography for measurement of RRI, PSV and EDV; eGFR was calculated from serum creatinine. Inter-stage differences were tested with one-way ANOVA and associations with eGFR with Pearson correlation; $p < 0.05$ was considered significant. ***Results:*** Mean age was 58.64 ± 5.2 years; 86% were male. The cohort spanned all five CKD stages, with Stage 3 (34%), Stage 4 (28%) and Stage 5 (20%) predominating. PSV declined progressively from 50.93 ± 1.32 cm/s in Stage 1 to 34.65 ± 1.81 cm/s in Stage 5, EDV fell from 19.13 ± 0.55 to 6.51 ± 0.82 cm/s, and RRI rose from 0.60 ± 0.00 to 0.81 ± 0.02 (all $p < 0.01$). RRI correlated inversely with eGFR ($r = -0.745$, $R^2 = 0.57$), while PSV ($r = 0.823$, $R^2 = 0.67$) and EDV ($r = 0.882$, $R^2 = 0.77$) correlated positively. EDV demonstrated the strongest correlation. No individual cardiovascular risk factor reached statistical significance against an RRI threshold of 0.70, although diabetes mellitus and coronary artery disease showed clinically meaningful directional trends. ***Conclusion:*** Renal Doppler parameters show robust, stage-wise, and statistically significant deterioration across advancing CKD, with EDV emerging as the strongest single Doppler predictor of renal function. RRI, PSV and EDV are accessible, reproducible and cost-effective adjuncts to eGFR-based staging and should be incorporated into routine CKD evaluation.

Keywords: Chronic kidney disease; Renal resistive index; Doppler ultrasonography; End-diastolic velocity; Peak systolic velocity; eGFR; Prognosis.

INTRODUCTION

Chronic kidney disease (CKD) is defined by persistent structural or functional alteration of the kidneys lasting more than three months. Its global prevalence has risen sharply over recent decades, now affecting at least one in ten adults worldwide, driven by ageing populations and the epidemic of obesity, hypertension and diabetes mellitus.1 CKD is a leading cause of death globally, with attributable mortality having risen from 0.6 million in 1990 to 1.4 million by 2019, and India alone accounts for approximately 115 million prevalent cases — nearly one-sixth of the global burden.2,3

Despite advances in pathophysiological understanding and pharmacotherapy, accurate stratification of patients at greatest risk of progression remains an unmet clinical need. Most conventional biomarkers — including serum creatinine, eGFR and proteinuria — quantify the consequences of nephron loss rather than the dynamic vascular processes that drive it.

Doppler ultrasonography of the intrarenal arteries offers a complementary, non-invasive, radiation-free window onto renal haemodynamics, with measurements that reflect intrarenal vascular impedance and arterial compliance.4,5

The renal resistive index (RRI), calculated as (PSV − EDV) / PSV, was originally introduced as a marker of arterial stiffness. In healthy adults RRI typically ranges between 0.47 and 0.70, with inter-kidney variation under 5–8%. Conditions that reduce vascular compliance or raise pulse pressure — advancing age, smoking, hypertension, atherosclerosis and CKD — elevate RRI. An RRI ≥ 0.70 has been associated with poorer renal survival, accelerated progression to dialysis and increased all-cause mortality in CKD, hypertension, diabetic nephropathy and post-transplant settings.6,7

Although the prognostic relevance of RRI is increasingly recognised, the individual contributions of its constituent velocities — PSV and EDV — have received less systematic attention, and their behaviour across the full KDIGO CKD spectrum has been incompletely characterised in Indian tertiary care cohorts. The present study was designed to evaluate the stage-wise behaviour of RRI, PSV and EDV and to compare their correlations with eGFR in a real-world hospital-based CKD population.

MATERIALS AND METHODS

Study design and setting

A hospital-based observational study was conducted in the Department of General Medicine, Mahatma Gandhi Medical College & Hospital, Jaipur, Rajasthan, between April 2024 and September 2025. The Institutional Ethics Committee approved the protocol, and written informed consent was obtained from every participant before enrolment.

Participants

Consecutive adults aged 18–65 years admitted with a diagnosis of CKD were screened, and 100 eligible patients were enrolled. Inclusion required a confirmed clinical diagnosis of CKD and willingness to provide written informed consent. Exclusion criteria were: kidney transplant recipients, documented renal artery stenosis, acute kidney injury, immunocompromised states (e.g., HIV infection, active malignancy), pregnancy, and active psychiatric illness or substance use disorder that could compromise study procedures.

Clinical and laboratory evaluation

All participants underwent detailed history-taking, including duration of CKD, presenting symptoms, comorbidities (hypertension, diabetes mellitus, coronary artery disease, dyslipidaemia, stroke, heart failure), smoking and obesity status, medication history and prior renal interventions. Standard physical and systemic examination was performed. Laboratory investigations included complete blood count, blood urea, serum creatinine, serum electrolytes, fasting and random blood glucose, urine routine examination and additional biochemistry as indicated. Estimated GFR was calculated and used to assign KDIGO CKD stage. Aetiology of CKD was classified from clinical records, biochemistry, imaging and previous biopsy reports where available.

Renal Doppler ultrasonography

Renal duplex Doppler ultrasonography was performed by experienced operators using standardised protocols. With the patient supine or in lateral decubitus position, the main renal arteries were identified by colour Doppler and interrogated at the segmental and interlobar arteries with the smallest possible insonation angle (< 60°). PSV (cm/s), EDV (cm/s), and RRI were recorded; for each kidney, indices were obtained from three reproducible waveforms and averaged. The mean of the two kidneys was used for analysis. Kidney size and corticomedullary differentiation were also documented.

Outcomes

The primary outcome was the relationship between RRI and CKD stage and its correlation with eGFR. Secondary outcomes were the corresponding relationships of PSV and EDV, and the association of an established prognostic RRI threshold of 0.70 with major cardiovascular risk factors and CKD aetiology.

Statistical analysis

Continuous variables were summarised as mean ± SD and categorical variables as frequencies and percentages. Inter-stage differences in PSV, EDV and RRI were tested with one-way ANOVA. Associations between Doppler parameters and eGFR were assessed with Pearson correlation, with R^2 reported as the coefficient of determination and 95% confidence intervals computed using the Fisher z-transformation. Categorical comparisons across RRI strata (< 0.7 versus ≥ 0.7) used the chi-square or Fisher's exact test as appropriate. A two-tailed p-value of < 0.05 was considered statistically significant.

RESULTS

Baseline characteristics

One hundred patients were enrolled. The mean age was 58.64 ± 5.2 years; 78% belonged to the 55–64 year age band, 12% to the 45–54 year band, and 10% were older than 65 years. Eighty-six per cent of the cohort were male. Hypertension was near-universal (96%), with diabetes mellitus in 54%, dyslipidaemia in 83%, history of coronary artery disease in 32%, current or past smoking in 42%, and obesity in 32%. Baseline characteristics are summarised in Table 1.

Table 1. Baseline demographic and clinical characteristics of the study population.

Variable	Value (N = 100)
Age (years), mean ± SD	58.64 ± 5.2
Age 45–54 years, n (%)	12 (12.0)
Age 55–64 years, n (%)	78 (78.0)
Age > 65 years, n (%)	10 (10.0)
Male sex, n (%)	86 (86.0)
Female sex, n (%)	14 (14.0)
Hypertension, n (%)	96 (96.0)
Diabetes mellitus, n (%)	54 (54.0)
Dyslipidaemia, n (%)	83 (83.0)
History of CAD, n (%)	32 (32.0)
Current/past smoker, n (%)	42 (42.0)
Obesity, n (%)	32 (32.0)

CAD, coronary artery disease.

CKD stage distribution

All five KDIGO CKD stages were represented. Stage 3 was most common (34%), followed by Stage 4 (28%) and Stage 5 (20%); Stage 2 and Stage 1 accounted for 12% and 6%, respectively. Patients with moderate-to-advanced disease (Stages 3–5) thus comprised 82% of the cohort, consistent with the tertiary care referral pattern.

Stage-wise behaviour of Doppler parameters

PSV declined progressively across CKD stages, falling from 50.93 ± 1.32 cm/s in Stage 1 to 34.65 ± 1.81 cm/s in Stage 5 — a cumulative reduction of approximately 32% ($F = 112.36$, $p < 0.01$). EDV showed an even steeper relative decline, from 19.13 ± 0.55 cm/s in Stage 1 to 6.51 ± 0.82 cm/s in Stage 5, equating to a 66% absolute reduction ($F = 186.54$, $p < 0.01$). RRI rose progressively from 0.60 ± 0.00 in Stage 1 to 0.81 ± 0.02 in Stage 5 ($F = 42.70$, $p < 0.01$), crossing the prognostic threshold of 0.70 between Stage 2 and Stage 3 and remaining above this value in advanced disease. Stage-wise data are presented in Table 2.

Table 2. Distribution of patients and stage-wise Doppler haemodynamic parameters across KDIGO CKD stages.

CKD Stage	n (%)	PSV (cm/s) Mean ± SD	EDV (cm/s) Mean ± SD	RRI Mean ± SD
Stage 1 (Egfr ≥ 90)	6 (6.0)	50.93 ± 1.32	19.13 ± 0.55	0.60 ± 0.00
Stage 2 (eGFR 60–89)	12 (12.0)	49.48 ± 3.23	17.22 ± 2.50	0.67 ± 0.06
Stage 3 (eGFR 30–59)	34 (34.0)	44.12 ± 2.96	12.69 ± 1.36	0.71 ± 0.04
Stage 4 (eGFR 15–29)	28 (28.0)	39.56 ± 2.70	9.72 ± 1.51	0.75 ± 0.05
Stage 5 (eGFR < 15)	20 (20.0)	34.65 ± 1.81	6.51 ± 0.82	0.81 ± 0.02
F value	—	**112.36**	**186.54**	**42.70**
p value	—	**< 0.01**	**< 0.01**	**< 0.01**

PSV, peak systolic velocity; EDV, end-diastolic velocity; RRI, renal resistive index. Inter-stage differences tested by one-way ANOVA.

Correlation of Doppler parameters with eGFR

All three Doppler parameters demonstrated highly significant correlations with eGFR. RRI showed a strong inverse correlation ($r = −0.745$, 95% CI −0.822 to −0.643; $R^2 = 0.57$; $p < 0.001$), indicating that 57% of the variation in eGFR was explained by RRI. PSV correlated positively with eGFR ($r = 0.823$, 95% CI 0.748 to 0.878; $R^2 = 0.67$; $p < 0.001$), and EDV showed the strongest correlation of all three parameters ($r = 0.882$, 95% CI 0.830 to 0.919; $R^2 = 0.77$; $p < 0.001$), accounting for 77% of the variance in eGFR. Correlations are summarised in Table 3.

Table 3. Correlations between Doppler haemodynamic parameters and eGFR.

Parameter vs eGFR	Pearson r	95% CI	R^2
RRI	**−0.745**	**−0.822 to −0.643**	**0.57**
PSV	**+0.823**	**0.748 to 0.878**	**0.67**
EDV	**+0.882**	**0.830 to 0.919**	**0.77**

CI, confidence interval; R^2, coefficient of determination. EDV emerged as the strongest individual Doppler predictor of eGFR.

Cardiovascular risk factors and elevated RRI

Eighty-eight of 100 patients had an RRI ≥ 0.70 and 12 had values below this threshold. None of the studied cardiovascular risk factors reached statistical significance as a binary correlate of elevated RRI (Table 4). Hypertension was near-universal in both groups (91.67% vs 96.59%; p = 0.44). Diabetes mellitus was more prevalent in the elevated-RRI group (56.82% vs 33.33%) and history of coronary artery disease showed a similar directional trend (34.09% vs 16.67%), although neither reached significance (p = 0.12 and p = 0.21, respectively). Smoking and obesity did not differ significantly between groups.

Table 4. Distribution of cardiovascular risk factors stratified by renal resistive index threshold (RRI < 0.7 vs ≥ 0.7).

Risk factor	RRI < 0.7 (n=12) n (%)	RRI ≥ 0.7 (n=88) n (%)	p value
Hypertension	11 (91.67)	85 (96.59)	0.44
Diabetes mellitus	4 (33.33)	50 (56.82)	0.12
Dyslipidaemia	9 (75.00)	74 (84.09)	0.46
History of CAD	2 (16.67)	30 (34.09)	0.21
History of stroke	1 (8.33)	7 (7.95)	0.96
History of heart failure	1 (8.33)	9 (10.23)	0.84
Smoking (current/past)	6 (50.00)	36 (40.90)	0.55
Obesity	5 (41.67)	27 (30.68)	0.46

CAD, coronary artery disease.

CKD aetiology

Diabetic nephropathy was the most frequent aetiology in patients with RRI ≥ 0.70 (57.95%) compared with those with RRI < 0.70 (33.33%). Conversely, undetermined causes (including tubulointerstitial nephritis and nephrosclerosis) were more prevalent in the lower-RRI group (58.33% vs 38.64%). Glomerular disease and cardiorenal syndrome contributed small proportions in both groups. The overall association between aetiology and RRI threshold was not statistically significant (p = 0.29).

DISCUSSION

This hospital-based study of 100 consecutive CKD patients demonstrates that intrarenal Doppler indices deteriorate predictably and progressively across the full KDIGO CKD spectrum, that all three velocities (RRI, PSV and EDV) correlate strongly and significantly with eGFR, and that EDV is the single most powerful Doppler predictor of renal function. These findings reinforce the case for routine integration of duplex Doppler into the clinical evaluation of CKD.

Demographic context

The mean age of 58.64 ± 5.2 years and 86% male predominance reflect the typical tertiary care CKD population in north-western India, where the combination of late presentation, high prevalence of diabetes and hypertension in middle-aged men, and differential healthcare-seeking behaviour drives the demographic skew. Toledo et al.7 (2015), in a cohort of 1,962 CKD patients, identified older age as an independent predictor of elevated RRI, attributable to age-related arterial stiffening that compounds CKD-mediated haemodynamic deterioration. The clustering of our cohort in the late middle-age band positions it in precisely the window where surveillance with Doppler is most clinically informative.

Progressive deterioration of Doppler indices

The 32% reduction in PSV and 66% reduction in EDV from Stage 1 to Stage 5 reflect progressive intrarenal vascular remodelling — glomerulosclerosis, arteriolar hyalinosis, interstitial fibrosis and tubular atrophy that simultaneously reduces vascular calibre, compliance and the volume of perfusable parenchyma. Hanamura et al.8 (2012), correlating RI with biopsy findings in 202 CKD patients, established a direct link between rising RI and these histological hallmarks, providing the structural basis for the haemodynamic changes captured in our cohort. Krishna et al.9 (2021) reported a

closely parallel stage-wise trajectory of RRI in diabetic nephropathy (0.61 in Stage 1 to 0.87 in Stage 4), supporting the external validity of our findings.

EDV as the strongest Doppler predictor

The most clinically actionable finding of the present study is that EDV outperformed both RRI ($R^2 = 0.57$) and PSV ($R^2 = 0.67$) in explaining the variance of eGFR, accounting for 77% of that variability on its own. This superiority is mechanistically intuitive. EDV reflects continuous forward perfusion during cardiac diastole, when flow depends on residual systolic kinetic energy and arterial elastic recoil rather than on cardiac systolic effort. Rising intrarenal resistance attenuates diastolic flow disproportionately and earlier than systolic flow, which is buoyed by cardiac output and aortic pressure until late disease. The disproportionate fall in EDV is in fact the mathematical driver of RRI elevation, and reporting EDV explicitly captures information that the composite ratio inevitably compresses. Vishruth et al.10 (2025) and Rehman et al.11 (2024) similarly highlight the centrality of EDV-driven changes in characterising progressive nephropathy, and our data argue for its routine inclusion alongside RRI in clinical reports.

RRI threshold and prognostic implications

Mean RRI crossed the established prognostic threshold of 0.70 between Stage 2 and Stage 3 and rose to 0.81 in Stage 5. This pattern aligns with the body of evidence linking RRI ≥ 0.70 with poorer renal and patient survival. Hanamura et al. (2012) reported significantly worse renal survival in patients with RI ≥ 0.7 and an absence of therapeutic response to steroids in this group. Toledo et al.7 (2015) showed that RRI ≥ 0.70 was independently associated with all-cause mortality in CKD even after adjustment for major confounders, and Kharsa et al.1 (2023) demonstrated that elevated RRI independently predicted both mortality (adjusted HR 1.04) and progression to dialysis (HR 1.06) in a 192-patient cohort. The Winther et al.12 (2012) RRI threshold of > 0.66 for identifying patients at risk of CKD Stage 4 or higher was already exceeded, on average, in our Stage 3 patients, suggesting that haemodynamic deterioration outpaces eGFR categorisation in some patients and that Doppler may serve as an earlier warning system.

Cardiovascular risk factors and aetiology

None of the studied cardiovascular risk factors reached statistical significance as a correlate of RRI ≥ 0.70 in our cohort. The near-universal prevalence of hypertension produced a ceiling effect that precluded detection of differential signal, although the pathophysiological and epidemiological link between hypertension and RRI elevation is robustly established in larger multivariable analyses (Toledo et al.7 2015; Gupta et al.13 2018). The directional clustering of diabetes mellitus (56.82% vs 33.33%; p = 0.12) and coronary artery disease (34.09% vs 16.67%; p = 0.21) in the elevated-RRI group is consistent with the work of Provenzano et al.14 (2020), who identified both diabetes and smoking as independent multivariable predictors of higher RI in 73 CKD patients. The clustering of diabetic nephropathy aetiology in the elevated-RRI group similarly reflects the accelerated intrarenal vascular injury characteristic of diabetes, captured by Doppler at any given level of eGFR (Talukdar R et al.15 2023). The non-significant univariate findings in our cohort most plausibly reflect limited statistical power and a single-centre cross-sectional design rather than absence of effect.

Strengths and limitations

Strengths of the study include the inclusion of patients across all five KDIGO CKD stages, the use of standardised Doppler protocols with averaging across multiple waveforms and both kidneys, and concurrent eGFR-based staging. Limitations include the single-centre observational design, modest sample size, predominantly male composition that may underestimate RRI prevalence in a sex-balanced population, absence of longitudinal outcome ascertainment (mortality, dialysis initiation), and absence of histological confirmation. Future work should incorporate prospective follow-up, multivariable modelling and biopsy correlation where feasible.

CONCLUSION

Doppler-derived intrarenal haemodynamic indices show robust, stage-wise, and statistically significant deterioration across all five KDIGO stages of CKD. RRI rises and PSV and EDV decline progressively with advancing disease, and all three correlate strongly with eGFR. EDV emerges as the strongest single Doppler predictor of renal function, explaining 77% of the variance in eGFR, and warrants explicit reporting alongside the composite RRI in clinical practice.

As a non-invasive, radiation-free, reproducible and inexpensive adjunct to biochemistry-based staging, duplex Doppler ultrasonography deserves systematic incorporation into routine CKD evaluation to support earlier risk stratification, monitoring of progression, and individualised therapeutic decision-making.

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